VIRTUAL CAMPUS TOUR GENERATION USING UAV DATA: CASE STUDY GEBZE TECHNICAL UNIVERSITY

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ABSTRACT: In recent years, with the remarkable development in game engines, virtual reality (VR) technologies, which immerse users inside a synthetic environment, became very popular and were increasingly integrated into the visualisation of geospatial data. In the Covid-19 pandemic, restricting people's mobility, the interest in VR visits was rapidly increased. In the scope of a scientific research project, a three dimensional (3D) virtual tour for Gebze Technical University Campus was generated by integrating very high resolution unmanned air vehicle (UAV) data into a virtual environment utilizing Unity game engine. Regarding high geolocation accuracy and spatial resolution, low cost, short processing time, and 3D realistic model generation performance, UAV data is largely demanded in varied scientific and commercial applications. In this study, the campus area was collected with 2.18 cm ground sampling distance (GSD) from 80 m flight altitude using 20 MegaPixel UAV digital camera. The UAV data was processed by Agisoft Metashape, structure from motion (SFM) based image matching software, and then high-quality 3D textured models were generated. The aerial imagery was oriented by ground control points (GCPs), carefully distributed in the study area. The geometric accuracy of the image orientation was calculated as ±8 mm (~0.4 pixels). For virtual reality integration, first, the 3D textured models derived from UAV data were imported into the Unity game engine. After that, optimization techniques including occlusion culling, space subdivision were applied to the models to prevent problems that may arise due to transferring high poly models to game engines. Thus, objects and textures have been transferred with the highest resolution to achieve a realistic virtual experience. For creating a more detailed and realistic environment, 3D models of trees, lighting poles, benches, arbours, and information panels were added to the model using available assets in Unity. Also, the metadata about buildings (e.g. building name, floor area and the number of staff) were added to the 3D building models. Finally, a player with a first-person camera is implemented for the virtual tour in the integrated 3D models. In this study, the encountered problems and recommended solutions for creating a virtual campus are presented.

1. INTRODUCTION

Virtual reality (VR) systems provide the ability to represent physical data in a synthetic environment and give users an immersive VR experience. With the improvements in game engines, VR systems became a field of interest, and VR-based applications gained increased attraction. Also increased number of free game engine software such as Unity, Unreal Engine offers new opportunities to users and developers. Lately, VR technologies are adopted in both scientific and commercial fields, boasting a number of applications. VR systems became an indispensable tool for geospatial data visualisation and producing high-quality 3D models in areas such as virtual tourism, cultural heritage documentation, forensic studies, archeological research, and even exposure therapy (Gaitatzes et al., 2001; Krijn et al., 2004; Koutsoudis et al., 2007; Putra et al., 2016; Koller et al., 2019; Doležal et al., 2019).

Latterly, the ongoing Covid-19 pandemic has limited people's mobility and virtual tours that enable remote visits, have become very popular. Some studies even suggest that VR tourism during the pandemic has become a source of revenue for various attractions and these remote visits also have a positive impact on the physiological well-being of the visitors (Itani and Hollebeek, 2021; Li et al., 2021). VR tours can be in different forms such as 360° virtual tours that are produced through the combination of panoramic images taken in different locations, and 3D virtual tours, created by the integration of high-quality 3D models into an artificial environment.

In this study, using very high resolution (20 MP) aerial photos derived by an unmanned air vehicle (UAV), a virtual tour of Gebze Technical University Southern Campus was generated. Currently, the UAV technology is very popular in remote sensing techniques with the quick acquisition of high resolution and accurate 3D data, used in varied applications such as cultural heritage documentation, archaeological surveys, inspections of engineering constructions and deformation analysis of natural disasters (Eisenbeiss and Zhang, 2006; Fernández-Hernandez et al., 2015; Yamazaki et al., 2015; Khaloo et al., 2018). With the generation of the 3D VR tour, candidate students, academicians, other visitors have a chance to visit the Campus remotely in a high-resolution artificial environment and get information about the terrain and non-terrain objects.

2. STUDY AREA AND MATERIALS

In the application, the Southern Campus of the GTU was used as the study area which covers 0.5 km^2. The topography is nearly flat and different land cover classes such as buildings, roads, and vegetation are available. Figure 1 shows the study area as a 3D textured mesh model. The flights were completed by using a DJI Phantom IV Version 2 UAV which was not able to make real time kinematic (RTK) positioning. That's why ground control points (GCP) were established in the study area and measured by CHC i80 Global Navigation Satellite Systems (GNSS) receiver. Following Table 1 presents the characteristics of the used UAV and GNSS receiver.

Figure 1. Study area as 3D textured mesh model

Table 1. Specifications of the used UAV and GNSS receiver

DJI Phantom IV Pro V2.0		**CHC i80 GNSS Receiver**	
Camera	4K, HD, 1080p, 1", effective pixels 20 MP	GNSS technology	GPS, GLONASS, GALILEO, BeiDou, SBAS, NavIC
Gimbal	3-axis (pitch, roll, yaw)	Operating system	Linux
Flight duration	Max. 30 minutes	Working modes	Static, VRS RTK, UHF RTK, all surveying modes
Weight	1375 g	Internal Memory	32 GB
Speed and Wind speed resistance	Max. 20 m/s and Max. 10 m/s	Positioning accuracy RTK	± 0.8 cm H, ± 1.5 cm V with initialization reliability > 99.9%
Operating temperature	0° to 40°C	Battery	Dual; Static up to 10 h, Cellular receive only up to 9 h, UHF receive/transmit up to 6 h
Outdoor positioning module	GPS/GLONASS dual	Network-RTK	Available
Hover Accuracy Range	± 0.1 m V, ± 0.5 m H (Vision); ± 0.3 m V, ± 1.5 m H (GPS)		

3. METHODOLOGY

In the processing of UAV aerial photos, structure from motion (SFM) based photogrammetric evaluation software Agisoft Metashape, Pix4D, Visual SFM and Context Capture are generally in use (Lucieer et al., 2014; Nesbit and Hugenholtz, 2019; Sefercik et al., 2019). In these software packages, 3D model generation is completed by using a dense point cloud, produced after aligning aerial photos based on the SFM algorithm. In this study, Agisoft Metashape software was preferred for the matching and geometric correction of aerial photos, dense cloud generation and filtering, and 3D textured mesh model production. For importing produced 3D textured mesh models into the virtual domain and designing a VR tour application, the Unity game engine was utilized. In Agisoft Metashape and the Unity game engine, followed steps were given in Figure 2.

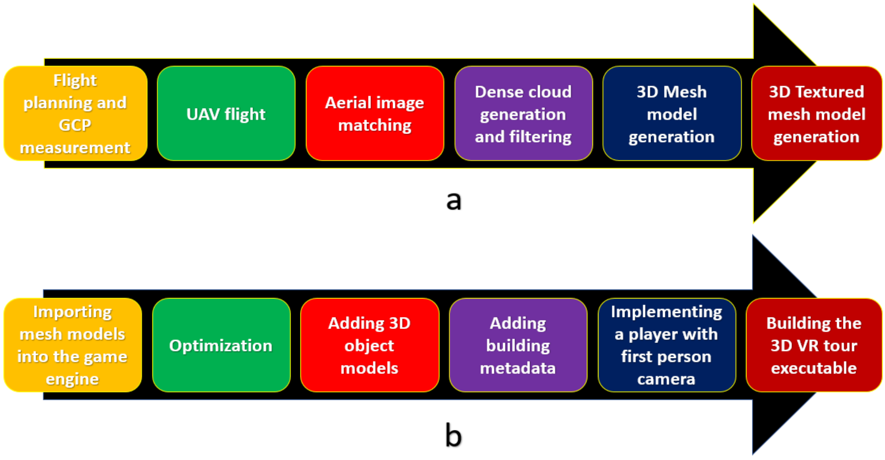

Figure 2. Processing steps in (a) Agisoft Metashape and (b) Unity game engine

In general, two ways exist to rectify UAV aerial photos and generate high accuracy 3D models. The usage of a RTK GNSS receiver equipped UAV or establishment of GCPs on the ground. Using a RTK GNSS equipped UAV is time saving because the user does not have fieldwork for GCP establishment and measurement on the ground for the rectification of aerial photos. However, RTK equipped UAVs are costly for many users which have limited budgets for research activities in underdeveloped or developing countries (Azim et al. 2019). In this study, as mentioned above, due to the lack of RTK GNSS equipment in the DJI Phantom IV Pro V2.0 UAV, GCPs were utilized for the geometric correction of the aerial images. In total, 43 polycarbonate GCPs were established over the study area. The established GCPs were measured by Continuously Operating Reference Stations (CORS) RTK GNSS technique with 0.8 cm horizontal and 1.5 cm vertical relative positioning accuracy.

In flight planning, the main aim was to cover the whole 3D modelling area with the minimum number of photos without any remarkable distortions and gaps. Therefore, using Pix4Dcapture UAV flight planning software, the entire area was covered by bundle grid, polygonal and circular flights. Bundle grid and circular flights were applied to the buildings for more realistic 3D building models. Where, 80 m altitude was preferred for the bundle grid and polygonal flights to achieve the GSD of ≤2.18 cm, circular flights were completed with an altitude of 30 m to obtain detailed data about building texture. In prepared flight plans, the minimum front and side overlap ratios were 80% and 60% respectively. Finally, a total of 5161 aerial photos were acquired with the flights. Figure 3 shows a sample view of polycarbonate GCP on an aerial photo and prepared flight plan over the study area. According to the flight plan, four bundle grid and three polygonal flights were realized.

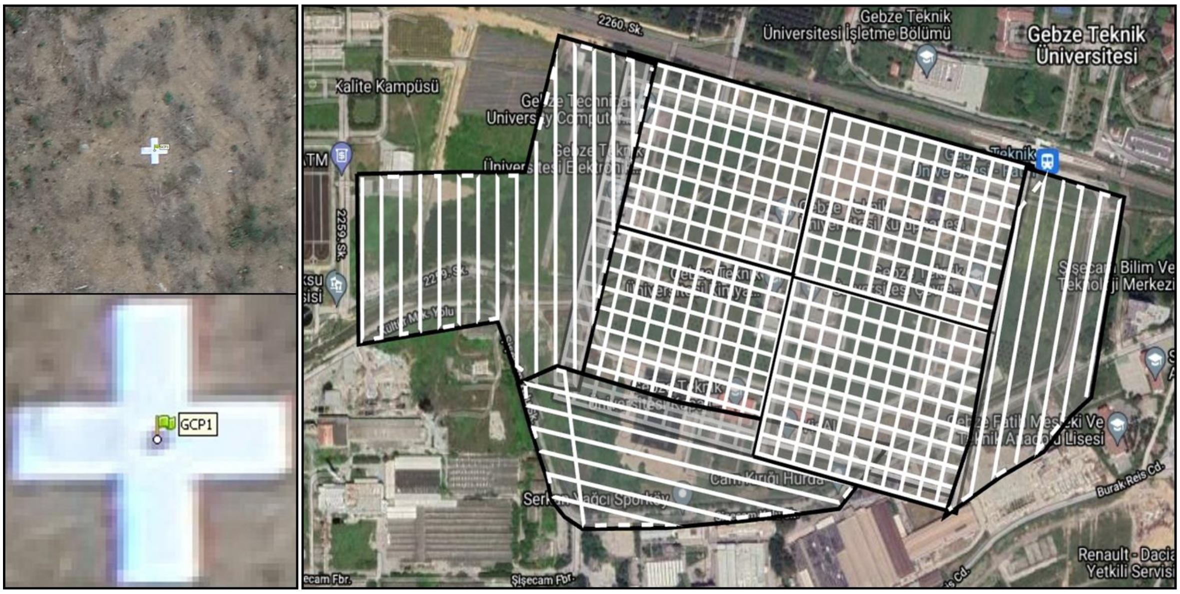

Figure 3. A sample GCP on an aerial photo and prepared flight plan

Orientation of aerial photos was carried out using Agisoft Metashape Professional software which operates based on the SFM algorithm. The SFM algorithm is a low-cost and efficient photogrammetric technique that allows the generation of 3D structures in high resolution by utilizing an array of offset photos with certain overlap ratios (Westoby et al., 2012). The SFM technique requires a series of offset photos with overlap to extract features and reconstruct 3D geometry. The orientation procedure consists of two main steps as the alignment of aerial photos and absolute orientation using GCPs. Before the initial image alignment, because of the sheer number of captured aerial photos and limited hardware capacity, obtained aerial imagery was imported into Agisoft Metashape as five different tiles. Camera calibration was carried out automatically for the determination of interior orientation parameters. Also, the oblique images with the background information have been masked to eliminate the disruptive effect of background pixels on the image alignment. After camera calibration and background pixel masking, initial image alignment was performed and a sparsely populated point cloud was generated. The absolute orientation was completed using GCPs with geometric accuracy of ±8 mm (~0.4 pixels). The geometric accuracy based on marked GCPs was automatically calculated as root mean square error (RMSE) in both meters and pixels according to Equation (1).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(\hat{X}_i - X_i)^2 + (\hat{Y}_i - Y_i)^2 + (\hat{Z}_i - Z_i)^2}{n}} \quad (1)$$

where $\hat{X}i$, $\hat{Y}i$, $\hat{Z}i$ = estimated values for i camera position
Xi, Yi, Zi = input values for i camera position

To produce a high-quality 3D mesh model, a high-resolution densely populated point cloud was generated by processing depth maps, built by extracting depth information from the image pairs with high overlapping values. In general, the generated dense point clouds have noise because of distortions in imaging geometry and the influence of land cover characteristics (especially forest). Of course, the noise may affect the quality of the generated 3D models. In this study, the noisy parts of the point clouds were classified and filtered. In addition, various objects such as cars, benches, lighting poles, and traffic signs were filtered as they might cause noise. Generated dense point cloud determines the objects in the non-continuous point-based format, so for proper visualisation and thus creating an immersive VR tour it was essential to reconstruct objects in 3D solid form. Therefore, processing dense point cloud data, 3D mesh models were produced. Due to the sheer number of predicted faces in the 3D mesh model preconstruction phase, the mesh decimation process was applied. 3D textured mesh model was generated by employing aerial photos to produce high-resolution textures and then applying these textures to 3D mesh models. The generated 3D textured mesh models were filtered because of contained isolated polygons and objects with rough geometry. Integration of the 3D mesh models into a virtual domain is essential in creating a 3D VR tour application. Efficient integration of 3D mesh models requires exporting them in a suitable format. Therefore, generated 3D textured mesh models were exported in Wavefront OBJ format and imported into the Unity game engine which supports OBJ files. Wavefront OBJ format stores coordinates of points, polygonal data of 3D models, and it is commonly employed and supported by an array of 3D computer graphics software (Kato and Ohno, 2009). Because of the large number of faces in imported 3D models and thus large polygon data, rendering optimization algorithms such as occlusion culling, and space subdivision were applied to the 3D VR tour application for increasing performance and efficiency. Occlusion culling algorithms are applied to identify, render visible sections of the 3D models, thus objects that fall behind the visible parts of a particular point of view are hidden and not rendered to increase the performance, eliminate hardware bottlenecks (Coorg and Teller, 1997). To improve the visualisation, 3D object models such as trees, lighting poles and arbours were positioned on the VR application. Furthermore, textual metadata about buildings such as name, total floor area, and total usage area was added to inform the visitors about the Campus. To construct an immersive VR tour experience, users should be able to walk around buildings and objects as if they are walking in real life. Therefore, a player with a first-person camera was added to the application for a realistic virtual experience. Finally, an executable file was built in Unity for the 3D VR tour application.

4. RESULTS

Figure 4 shows the generated sparse point cloud, dense point cloud, filtered dense point cloud and 3D textured mesh model of the study area. The point clouds were generated by merging five studied tiles. The dense point clouds of the independent tiles were generated in high resolution and the description potentials of the clouds were sufficient even in building corners.

Figure 4. (a) Sparse point cloud, (b) dense point cloud, (c) filtered dense point cloud and (d) 3D textured mesh model of the study area

3D textured mesh models were produced in high quality however small distortions exist due to the interpolation effects on particularly non-continuous vertical objects such as rooftop walls and eaves. Figure 5 shows the development of the 3D VR tour application in the Unity game engine. Figure 6 displays samples from the first-person point of view of the created 3D VR tour application. By means of very high-resolution UAV data, the contents of the Campus were introduced in detail successfully.

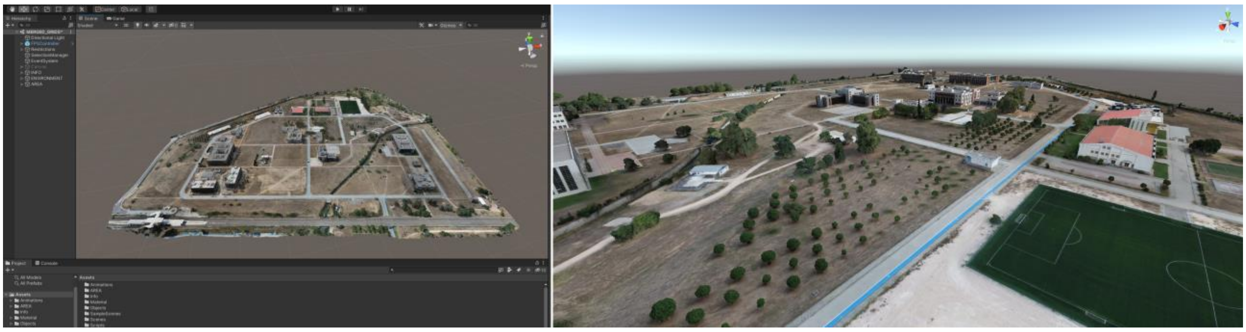

Figure 5. Development of 3D VR tour application in Unity

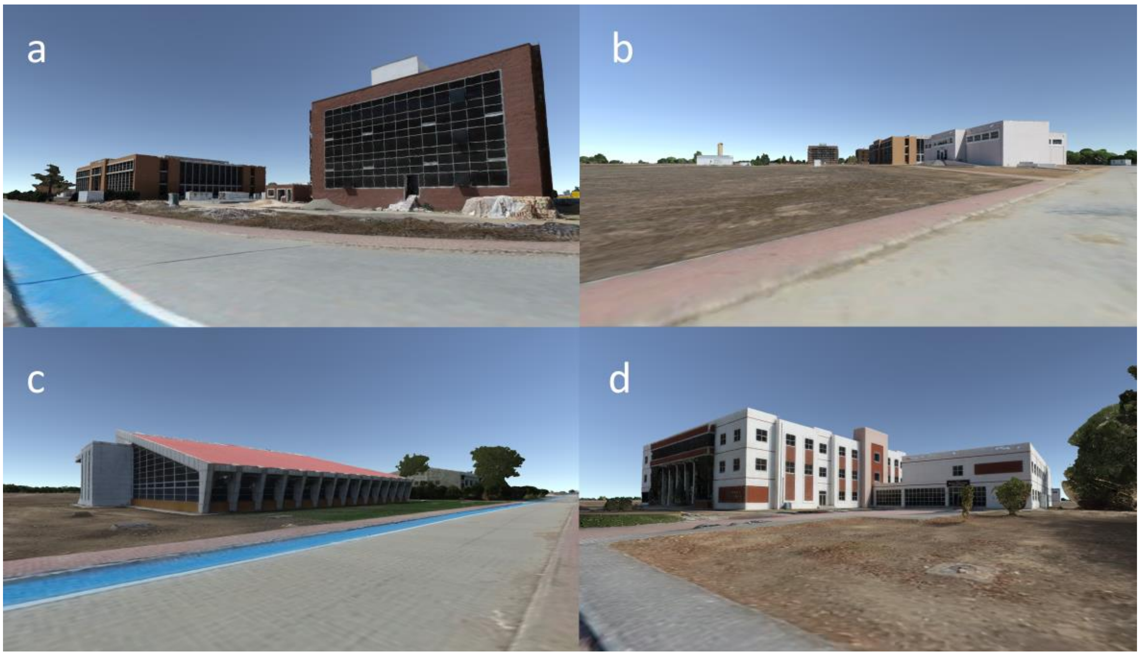

Figure 6. Some sample scenes from the 3D VR tour application in first-person point of view (a) Faculty of Basic Sciences, (b) Faculty of Earth and Marine Science, (c) swimming pool, (d) Department of Molecular Biology and Genetic

In the VR application figure (Figure 7), premade 3D object models such as trees, lighting poles and arbours, placed for better visualisation, can be seen. In addition, interactive information panels with the pop-up window feature were located near buildings to display textual metadata.

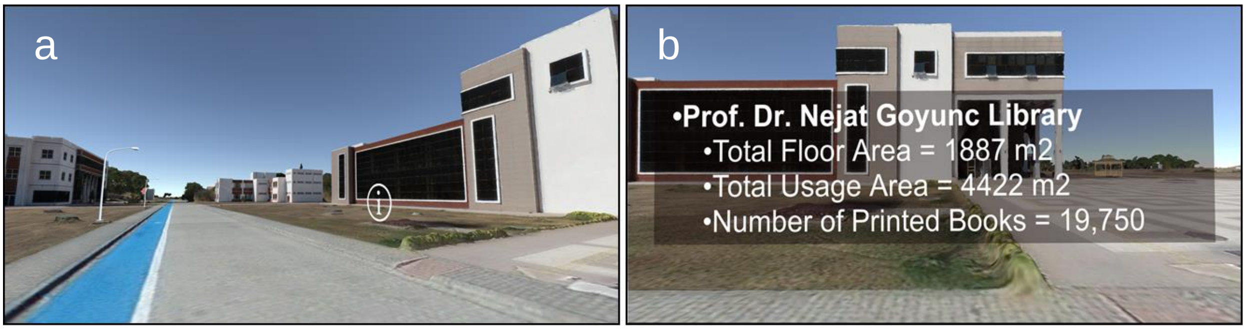

Figure 7. (a) Information panel symbol in the 3D VR tour application and (b) the pop-up window showing the textual metadata about the building

The achieved results demonstrated that the 3D VR tour application offers users the opportunity to explore realistic 3D models, collect information about Campus contents remotely, and have an immersive virtual experience.

5. CONCLUSIONS

The Covid-19 pandemic causes lots of negative effects on human life. Due to limitations in human mobility, virtual visits became more popular than ever. In this study, the 3D VR tour application of Gebze Technical University Southern Campus was created using DJI Phantom IV V2 high resolution 3D textured mesh models for both candidate and existing students, academicians and other visitors. The 20 MP UAV aerial photos were collected by polygonal, bundle grid and circular flights and oriented by 43 independent GCPs with RMSE of ±8 mm (~0.4 pixels). Generated high-quality 3D textured mesh models in Agisoft Metashape were integrated into the virtual domain by the Unity game engine. The reality of the virtual tour was improved by adding 3D object models such as lighting poles, trees, arbours, benches. Also, the textual metadata about buildings such as name, total floor area, total usage area was added to inform users about the Campus contents during the VR tour. Finally, a player with a first-person camera was integrated for a realistic VR experience. Overall, thanks to the high-resolution UAV data, a successful 3D VR tour application was achieved.

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