Generation of High-Resolution 3-D Maps for Landscape Planning and Design Using UAV Technologies

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Abstract: To support the decision-making process and to share ideas easily and make them quickly accessible to users, new digital tools are gradually being developed from two-dimensional and three-dimensional levels, to the fourth dimension. Traditionally, remote sensing images, including aerial (unmanned or manned) or satellite systems, are used to collect geospatial data. Unmanned aerial vehicles (UAVs), however, have recently become a suitable technology for providing exceptionally high spatial and temporal resolution data at a lower cost than other remote sensing data. Landscape architects using UAVs for versatile flying platforms for various sensors and photogrammetric software can create 3-D models faster than traditional topographic research methods. This study aims to demonstrate the potential of using UAVs for obtaining 3-D topographic data from various types of UAVs that can be used as a basis in landscape planning and design studies. This study proposes an established 3-D data generation workflow and its use in landscape design and planning applications using a fixed wing UAV with a GoPro 4 camera having 12 MP CMOS Sensor, and a quadcopter with 20 MP CMOS Sensor to collect image data for 3-D maps using photogrammetry. This study shows that UAVs provide promising opportunities for creating high-resolution and precise images, thus making 3-D mapping easier.

Keywords: UAVs, 3-D terrain maps, landscape planning

1 Introduction

In Geographical Information System (GIS) data, three-dimensional (3-D) terrain visualization has recently become an important topic. GIS applications are moving toward 3-D because they have the ability to express the real world in a better way. Over the past decade, researchers have been working on cartographic specifications, design principles, and visualization techniques to further improve efficiency and effectiveness in 3-D landscape modeling and mapping. HAEBERLING (2002, 2005) described the most basic term *3-D map* as a computer-generated view (representation) of a 3-D integrated geo-data model with cartographic content, i. e. in compliance with traditional cartographic symbolization and generalization. Today, 3-D modeling and mapping are key components of an increasing number of diverse applications and have a wide range of users for purposes such as city planning, landscape monitoring, utility and transportation management, tourist maps, and 3-D mapping services (DINKOV & VATSEVA 2016).

In recent years, cost-effective, unmanned aerial vehicles (UAVs) have begun to play a major role in the development of 3-D spatial data. In terms of available sensor equipment, time, and flight planning, UAVs provide users with great flexibility. UAV systems can include thermal, multispectral, hyperspectral video cameras or Laser Imaging Detection and Ranging (LIDAR) sensors depending upon to their carrying capacities. UAVs record spatial positions with high accuracy by synchronizing the sensors' data and the Global Navigation Satellite System/Inertial Navigation System (GNSS/INS). The images obtained from UAVs are used effectively and efficiently in the fields of civil and scientific research activities in different fields of application. Agriculture (GRENZDÖRFFER & NIEMEYER 2011), mapping (NEX & REMONDINO 2014), surveying and cadastral applications (CUNNINGHAM et al. 2011, MANYOKY

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et al. 2011, CRAMER et al. 2013, BARNES et al. 2014), archaeology and architecture (CHIABRANDO et al. 2011), geology (EISENBEISS 2009), coastal management (DELACOURT et al. 2009), disaster management (CHOI & LEE 2011, MOLINA et al. 2012), damage mapping (VERTIVEL et al. 2015), cultural heritage (REMONDINO et al. 2011, RINAUDO et al. 2012), urban planning, and landscape architecture, all use 3-D data at a much lower cost than traditional aerial photogrammetry. Data collected by UAVs are used in topography as well as in studies such as flood risk, vegetation cover, landscape monitoring, and recreational activities based on planning and design projects in landscape architecture. In this study, we aim to show how to analyze 3-D data on different scales with low cost and high precision from different UAV types in landscape planning and design studies. In this context, this study consists of three stages: image acquisition, image processing, and GIS analysis.

2 Materials and Methods

2.1 Study Site

This study was performed on two different scales of landscape to illustrate the use of images from UAVs. Therefore, two study areas were selected. The first study site is located in the mountainous region where a 48 km^2 hydroelectric power plant and excavation area will be constructed in the north of Adana Province. The altitude here is between 830 and 1100 m. The second study site is located on the Çukurova University Faculty of Architecture campus, which is to be built in Adana Province. The altitude of the second study area is between 79 and 91 m and slopes gradually up toward the north-west of the site.

2.2 Methods

The study methodology consists of three steps: UAV image acquisition in areas with different characters on different scales, image processing and production of 3-D data, and GIS analysis for landscape planning and design studies (Figure 1).

2.2.1 Remotely Sensed Data Collection

Two different UAVs were used in this study: fixed wing and quadcopter. The reasons for this are the different sizes of the study areas, different spatial resolution data demand, and different flight time and camera features of the UAVs. Because of the highly variable topography and weather conditions, fixed wing was used for the first study area The fixed wing used has a 2 m wingspan and a flying time of 60 to 80 min with 5 kg payload. Under turbulent wind conditions, it exhibits stable flight. This UAV has GoPro Hero 4 camera with 12 MP CMOS sensors at a staggering 30 frames per second. The camera has a lens focal length of 21.9 mm and a field of view of 94.4. The camera was inserted into a gimbal to provide rare orientation during image capture. The quadcopter used for the second study site has a 30 min flying time with 907 g take-off weight at a consistent speed of 50 km/h with no wind. The quadcopter was chosen to provide safer flight at low altitude and to obtain a higher ground-resolution image. DJI Mavic 2 Pro Quadcopter has a 20 MP CMOS sensor with a focal length of 35 mm and a field of view of about 77. The camera is placed in a three-way gimbal and can be fixed at the desired angle (Table 1).

Table 1: Study site and UAVs technical information

		Study Site – 1	**Study Site – 2**
			
Study area	Location	HEPP construction area on Zamanti River in Taurus Mountain	Cukurova University, Faculty of Architecture Construction Site
	Area	48 km^2	0.22 km^2
	Elevation	830 and 1100	79 and 91
UAV	Type	Fixed wing	Quadcopter
	Payload	5 kg	0.907 kg
	Flying time	60-80 min	30 min
	Resolution	12 MP	20 MP
	Focal length	21.9 mm	35 mm
	Field of view	94.4°	77°

Flight planning is one of the important stages when using UAV for aerial image acquisition. Flight planning, flight permit, detailed analysis of the area, and the pixel resolution (pixel size) should all be considered for the purpose of the study. Furthermore, technical equipment for flight height, GNSS, INS system and ground control points should be considered. The quality of the final product to be used for mapping depends largely on the quality of the images obtained. High overlaps between images (such as 70 %) are used to improve the quality of the final products, particularly for intensive image matching. This is because high overlapping image retrieval allows the correction of gaps due to possible platform imbalances.

2.2.2 Image Processing

In photogrammetric applications, the camera captures overlapping images in flight and generates data such as point finding, orthophotos, or 3-D models of the area. The Global Positioning System (GPS)/GNSS device on the UAV also stores the geographic references of these data. However, since low-cost UAVs have limited GPS/GNSS accuracy, ground control points (GCPs) are often obtained from the points that represent the study area. The UAVs used for the two study sites carry consumer-grade GNSS (L1, code signal, expected absolute position accuracy 5 – 10 m) so that high-quality GCPs were collected to accurately produce geo-referenced products. These points are measured from static objects that can be easily identified in UAV images, and it is possible to accurately map large areas even with a few known coordinates. Independent tests show that for accurate results fewer GCPs are needed than generally assumed. The Nevada Department of Transportation says that placing at least 5 to 10 GCPs with different elevations gives great advantage.

The main purpose of photogrammetry is to acquire 3-D information from 2-D images. For this purpose, the interior/exterior orientation, camera position, focal length, and lens distortion and rotation of the optical axis must be calculated on images. Once these parameters are available, the next step is to create dense point clouds. These point clouds should be configured for photo-realistic representation and visualization and, if necessary, interpolated, simplified, and textured (NEX & REMONDINO 2014). There are plenty of licensed or free software to do these automatically. In this study, the images were processed using Pix4D Mapper photogrammetric software. Pix4DMapper photogrammetry software allows you to create professional 3-D models and maps from images. With this software, images are converted into highly accurate, geo-referenced 2-D maps and 3-D models. Three-dimensional maps are customizable and complement a wide range of applications and software. Pix4DMapper Professional software is chargeable and uses images to create photogrammetry software, point clouds, digital surface and terrain models, orthomodels, textured models, and more.

The software has many basic outputs and features. It stores X, Y, and Z positions and color rendering of data with an intensified 3-D point cloud. It can be used in any GIS software by recording the height value of each pixel with a digital surface and terrain model. With Ortho mosaic, it enables the production of a geographically located high-resolution map, where each pixel of the original images is projected into the digital surface model. It provides the display of topographic strokes indicating height and generates real textured triangles to form a 3-D textured model.

2.2.3 GIS Analysis

The produced 3-D and orthophoto maps were used as input data for GIS analysis of different scales.

- Landform analysis: This part of the study aims to classify the landforms of the first study area by morphological analysis with topographic positions index (TPI) using GIS. Morphological parameters such as slope, curvature, height difference, and topographic aperture are used to generate the land morphology. The Jennes algorithm used in the TPI calculation uses a multi-scale approach by placing a quadratic polynomial in the specified window size using the least squares (JENNES 2006). Using TPI on different scales and slope data, it classifies an area according to both slope status (ridge, valley floor, middle slope, etc.) and terrain form (steep narrow canyons, wide valley, plains, open slopes, etc.). The simple basis of the developed algorithm system is the height value of a pixel and the average value of neighboring pixels around that cell. If the resulting value is positive, it means that the pixel is higher than the other pixels and that negative value is low. In addition, the degree of inclination of the pixel is also considered in some classes. These regions are classified as peaks or ridges if a cell is significantly higher than neighboring cells. Significantly, lower values compared with neighboring cells indicate that the cell is near or at the bottom of the valley. Near-zero values are classified as flat areas or moderately sloping areas. In this case, there is a difference between flat areas and moderately inclined areas, taking into account the degree of inclination.
- Rehabilitation project (Planting design): The topographic data of the hydroelectric power plant construction excavation areas were obtained from the UAV, and a rehabilitation project was planned to prevent the soil erosion. Topographic data are generated for the

areas where vegetation should be established to bring these areas back to more natural conditions and reduce the risk of erosion. To break the length of slope and stream linear sediment barriers (silt fences, sandbag barriers (blocks, sets), and straw bale barriers), fiber spiral (rolls), gravel bag or sediment traps should be used efficiently. Sediment barriers are used at the bottom of the slopes that are exposed to the effects of stream and surface stream erosion as well as those losing protective vegetation as a result of construction activities. Sediment barriers are also used around the soil storage and construction site and on the lower slopes of the soil separated from the topsoil. Planting activities must be done according to landscape restoration and improvement targets and mentioned principles.

- Landscape Design Project: Realistic 3-D modeling has been realized by designing landscape projects for the Cukurova University Faculty of Architecture. An exemplary landscape design project for the area was modeled in the 3-D model to integrate with the topographic data produced by UAV.

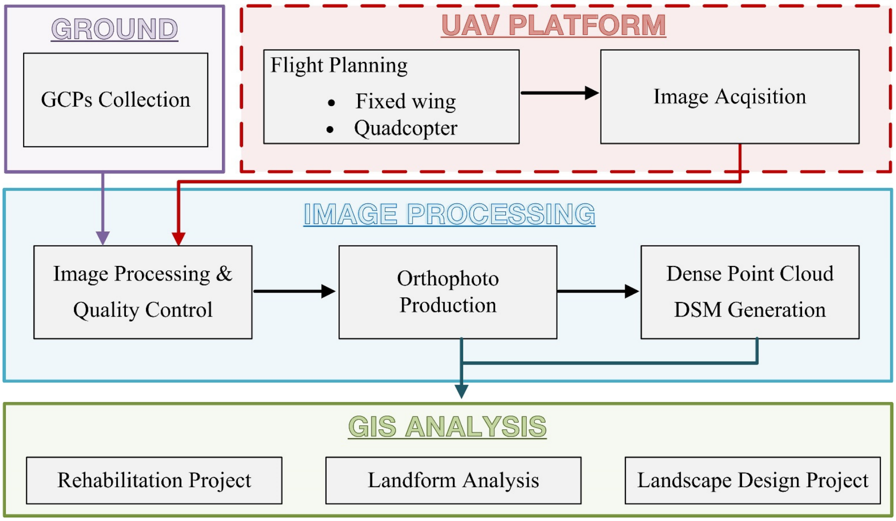

Fig. 1: Overall process flow of the study

3 Results

The UAV flights for the first study area took place in August 2017 using fixed wing, whereas the second study area was done in September 2018 with DJI Mavic Pro 2 quadcopter. Two- and nine-row automatic flight plans at 1000 and 50 m height, respectively, are defined. For the first study area (48 km^2), 408 geotagged nadir images with 1 m spatial resolution were collected in the mountainous area with 60 % and 70 % lateral overlap. Images were taken at noon in a period of 1 hour to minimize shadows in the resulting image. The flight time on the work area, including take-off and landing, was about 3 hours, and it took about 3 days to identify and mark GCPs in the image and image direction on a good computer, with intensive image matching, and orthophoto creation. The camera attached to the fixed wing is a fisheye lens that captures images using a roller shutter sensor. Fisheye lenses have the advantage of obtaining a wide field of view and high-resolution images, but they require special camera calibration models to produce results comparable with conventional perspective cameras (Strecha et al. 2015). Distortions attributed to the fisheye lens of the UAV camera can be visible in the areas bordering the image block. Furthermore, the cameras installed in the UAV are not metric, so self-calibration is mandatory. Additional distortions could also be considered and modeled when the UAV is flying very fast or when there are dynamic objects to be captured. For the second study area (0.22 km^2), 496 images with 2.4 cm spatial resolution were collected at the Çukurova University Faculty of Architecture campus along nine lines at 50 m above ground level with 70 % lateral and forward overlap. Nine ground control points for the first study area and 11 GCPs for the second area were identified within the study area, and the coordinates of the points were determined precisely with a GPS with the GNSS. Thus, high-accuracy geographic correction is applied to all images.

After image orientation, intensive matching was initiated using the full resolution of the images to create a very dense point cloud using Pix4D Mapper photogrammetric software. The software used a patch-based approach. This process led to the creation of millions of points interpolated into DSM. Using the resulting DSM, orthophoto correction was performed to eliminate relief distortions and produce a true orthophoto. Low accuracy is primarily due to insufficient accuracy of navigation class GNSS units used to record camera position during image acquisition. Low vertical accuracy may result from the UAVs recording of the relative height above the take-off point, not the absolute height of the drone on the image geotags. In this study, the absolute height was obtained by subtracting the height of the take-off point determined by a high-accuracy GNSS receiver, and potential errors were eliminated in the final model. In orthophoto production, the location of GCPs has gained great importance for obtaining high-precision images. High-quality RGB orthophotos were obtained with an eight-bit radiometric resolution with 1 m and 2.4 cm positional resolution, where the landscape features are clearly visible to the eye. These generated high-resolution 3-D data were produced for use in GIS studies on different scales.

- Landform analysis: In this section, 3-D data obtained by UAV is applied as an example of the production of land morphology data. TPI values were calculated using two different neighboring distances with radii of 300 and 2000 m. The canyons and their side connections were extracted in detail from the data with a radius of 300 m, whereas the general canyon system, from the data with a radius of 2000 m. After the TPI data were generated, landform data were generated using GIS software. They were produced to contain 10 classes (Fig. 4). The morphological classes include i) canyons and deeply incised streams, ii) mid-slope drainages and shallow valleys, iii) upland drainages and headwaters, iv) U-shape valleys, v) plains, vi) open slopes, vii) upper slopes and mesas, viii) local ridges/hills in valleys, ix) mid-slope ridges and small hills in plains, and x) mountain tops and high ridges. Landscape analysis and mapping techniques, as well as GIS and remote sensing techniques based on geomorphological analysis, may be important for researchers working on topics such as ecology, soil, geology, and planning.

Table 2: General information about flight planning and image processing

		Study Site – 1	Study Site – 2
			
Flight planning	Date	August 2017	September 2018
	Flight line	2	9
	Flight height	1000 m	50 m
	Overlaps	60 % forward and 70 % lateral	70 % forward-lateral
	Flight time	65 minutes	16 minutes
	GCPs	9	11
Image Pro-	Geotagged images	408 frames	496 frames
	Spatial resolution	1 m	2.4 cm

- Rehabilitation project (Planting design): The 3-D topographical data produced with the images from fixed wing are used to rehabilitate the natural areas damaged due to excavation. With the digital elevation model produced using UAV, it is possible to obtain data from the field in a short time and to work on more areas. Thus, a suitable landscape rehabilitation method was determined and detailed for addressing the damaged areas. At this stage, planting areas, and erosion prevention applications were applied to two areas that were specified in the project area. In the areas for which the degree of curvature was close to flat, straight reforestation with natural vegetation is possible. In the areas where the degree of curvature began to increase, terraces should be established to create proper grounds for planting. Conservation measures were developed by evaluating the project area and the surrounding area in an overall manner (Figure 2).

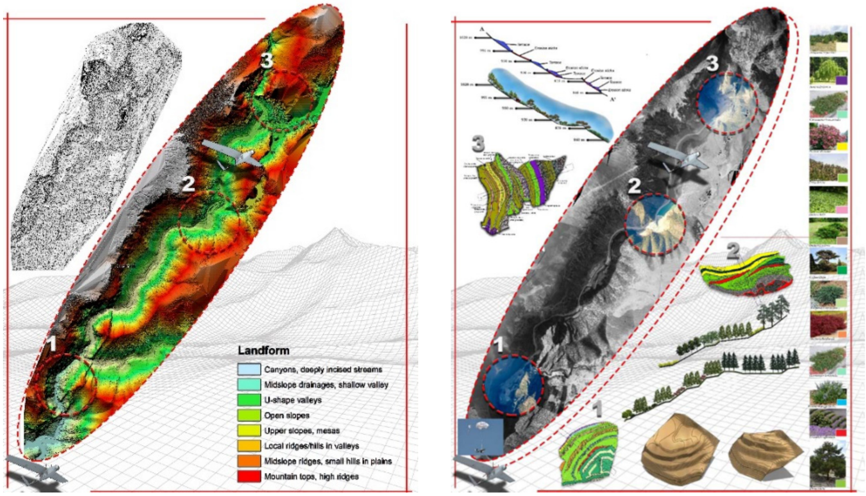

Fig. 2: Application of orthophotos produced from UAV data for landform analysis (left) and landscape rehabilitation project (right)

- Landscape Design Project: Different landscape projects were designed for the Cukurova University Faculty of Architecture campus. Three-dimensional modeling of these projects was integrated with 3-D data collected from UAV. In addition, realistic 3-D modeling was made by integrating the modeling with the topography (Figure 3).

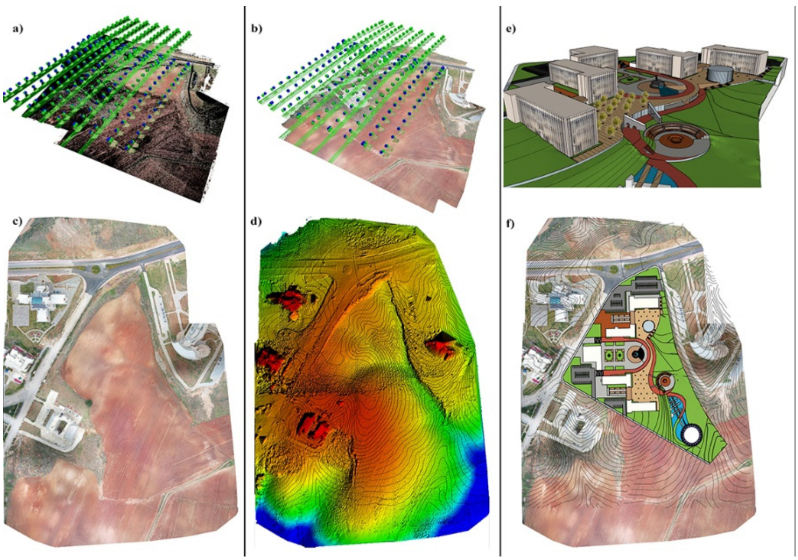

Fig. 3: The Çukurova University Faculty of Architecture campus (point cloud (a), surface modeling (b), orthophoto (c), digital elevation model (d), 3D render of project (e), overlapping project with the orthophoto (f)

4 Conclusion and Outlook

UAVs offer a variety of applications for landscape architects, from field analysis at the project stage to awareness raising in a completed project. Moreover, rapid developments in both UAV platforms will increase the coverage per flight, and photogrammetric software will facilitate the processing of larger projects in the future. In this study, the process of obtaining orthophotos and 3-D data on landscape planning and design scale with two popular UAV types is explained. In the first area, because of the large working area, a fixed wing UAV with high flight time and wide camera angle was used. A single flight provided the ease of obtaining the entire view of the work area. Since the drones have higher maneuvering capacity than airplanes, higher ground-resolution images were obtained with low altitude flight. Thus, detailed spatial input data were obtained for landscape design studies requiring larger scales. In addition, using UAVs is suitable for the study of areas with different area sizes. Spatial and temporal resolution were improved, and time involved and costs were lowered. As a result, there are promising opportunities for creating high-resolution, highly accurate orthophotos with low-cost UAV and photogrammetric techniques, making it easier to create and update maps. The generated data can improve the design and planning process and improve the interaction and cooperation in the planning process using GIS.

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