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Topographic Surveying using Low-Cost Amateur Drones & 4K Ultra-High-Definition Videos

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Abstract

These days, the science of photogrammetry is frequently used in a wide range of applications, including engineering geology, medication, security, navigation, and topographic surveying works. Drones have gradually become an effectual and frequent technique for obtaining a number of photogrammetric products, such as ortho-mosaics, Digital Elevation Model (DEM), and land detailed topographic maps. This paper investigates the possibility of employing low-cost amateur drones with 4K Ultra-High-Definition (UHD) video for topographic surveying works and creating DEM's. DJI Mavic 2 PRO drone with Hasselblad L1D-20C 20 MP camera has been used for covering an expected gas & oil pipeline route in the South of Libya with length of nearly 15 km and width of 200 m. 60 well-distributed high-quality 3D ground points, divided as 30 Ground Control Points (GCP's) and 30 check points, have been used for more stable and robust photogrammetric processing and for reliable evaluation, respectively. The camera has been calibrated twice, before and after executing the flight mission for trustworthy Interior Orientation Elements (IOE's). The recorded video has been split into smaller videos based on the capturing time of the required frames, and the small videos have been extracted to individual UHD photos using Matlab image tools. Leica Photogrammetric Suite (LPS) software has been used for all processing steps, except the automatic filtration of the generated tie points, which has been carried out using self-developed Matlab algorithm for epipolar geometry and 2D transformation based filters. Results show that DEM's with quality of nearly 1.2 to 2 decimeter in plane and elevation, respectively can be obtained using DJI Mavic 2 PRO drone, 4K UHD video taken by Hasselblad L1D-20C 20 MP camera, pixel ground footprint of 8 cm, and flight height of 350 m. This level of accuracy is appropriate for many engineering applications, such as initial-planning projects stretched on huge areas, urban development plans, GIS data collection, inventory of earth works materials, and 3D modeling. The obtained quality of the generated DEM depends on the flight height and the camera quality, IOE's, and resolution. Tests show that using 4K UHD video for photogrammetric applications can provide UHD extracted frames, similar to that captured singly, especially with fit flight speed and camera settings, namely: ISO sensitivity, shatter speed, and aperture size. Also, using video facilitates the aerial photography process, overcoming the difficulties of determining the suitable capturing time and location of individual photos in site. The other advantage is the ability of taking alternative frames if the selected images are not suitable for photogrammetric works in terms of tilting and blurring. The opportunity of changing the overlapping rates across the route is another important advantage of using video, especially for curvy routes. Moreover, using different groups of overlapped images for the same route helps for creating different DEM's for the same area, resulting more precise and dense topographic surveying works.

Keywords: Low-Cost Drones; Topographic Surveying; Digital Elevation Model; 4K Ultra-High-Definition Videos

1. Introduction

Photogrammetry is the art and science of taking measurements from aerial, space and terrestrial photos [1]. These days, photogrammetric applications are used in a wide range of subjects, such as vision navigation [2], rail-track monitoring [3], engineering geology, medication, security and topographic mapping [4]. With high-resolution space, aerial, and

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terrestrial photos and precise geo-referencing methods, photogrammetric products can provide a high-quality 3D information. This is of course in addition to the precise Automatic Image Matching (AIM) methods and effective matching filters [5]. Photogrammetry has many well-known advantages over the typical mapping methods, including 1) the high-capability to deal with inaccessible and difficult areas, such as military zones, high mountains and dense forests, 2) saving time, cost and efforts, 3) high safety, and 4) providing actual 3D detailed views. On the other hand, photogrammetric processing is complicated in terms of dealing with relief, tilting and lens distortions [6]. The other main drawback is the high-need of GCP's for precise and robust geometry of Self Calibration Bundle Block Adjustment (SCBBA), especially when the observed Exterior Orientation Parameters (EOP's) of camera are not reliable because of using stand-alone Global Positioning System (GPS) receivers [7, 8], low-cost GPS/Inertial Navigation System (INS) integration [9], or working without navigation sensors. Drones have become progressively an effective and familiar way for obtaining the main photogrammetric products, such as ortho-mosaics, DEM's, and land detailed topographic surveying maps [5]. Drones that are designed specifically for engineering surveying and photogrammetric applications tend to be high-priced, as they provided with special features, including high-resolution metric cameras, and high-quality GPS/INS suitable for Real Time Kinematic (RTK) and post processing carrier phase differential GPS. Different levels and methods of GPS/INS integration tend to be used in surveying drones based on the required level of accuracy for the photogrammetric products. For more details about such integration ideas, see [10, 11]. Examples of the famous surveying drones are Wingtra-One GEN II, DJI Phantom 4 RTK, and DJI Matrice 300 RTK [5]. Low-cost drones that are designed for amateur purposes have also become used for photogrammetric applications and products. Examples of the low-cost amateur drones are DJI Mavic: 1, 2, and 2 PRO. The quality of the obtained photogrammetric products is a function of the quality of the navigation and vision sensors used in the drones. Based on [5], with 4k UHD 20 MP camera, DJI Mavic 2 PRO can provide 3D Object Space Coordinates (OSC's) with accuracy of less than 10 cm in plane and about 13 cm in height from a flight height of 150 m, and accuracy of 13 cm and 18 cm in plane and height, respectively from a flight height of 215 m.

For good photogrammetric products, low-cost amateur drones need a good flight mission planning to set the camera for taking aerial images in the right positions based on the design flight speed, air base, flight height, etc., where these drones are not designed for capturing photos automatically in specific points. This means that if the captured image is not suitable for photogrammetric processing because of blurring, over tilting, etc., the image should be retaken again from the same position, height and direction, which is time-consuming, costly, and may not be possible. To overcome this problem, extra backup images can be captured by reducing the camera time interval. However, in some low-cost drones, the camera timing feature is not available; so, aerial photos should be captured manually in the required stations, which is high-complicated and timewasting. The other possible solution is to set the camera to take the maximum number of frames per second, taking into account the balance between drone flight speed and camera shutter speed [5]. Recording video is another possible solution, which can simplify the flight mission planning and calculations. The recorded video can then be extracted to individual frames. Both in case of using maximum frames or recording video, the required images can be chosen automatically based on the required overlapping rate, flight speed, flight height and camera IOE's. The chosen images should also be checked manually for the amount of clarity and quality to be suitable for AIM techniques. In this paper, utilizing low-cost drone for creating DEM's using 4K UHD video camera will be investigated. DJI Mavic 2 PRO drone will be used for covering an expected gas & oil pipeline route in the South of Libya 15 km long and 200 m wide. The quality of the results will be evaluated based on a significant number of well-distributed check points and the advantages and limitations of the applied idea will be discussed.

2. Drone & Camera Description

The drone used in this research is DJI Mavic 2 PRO and the camera is Hasselblad L1D-20C. Figure (1) shows the used drone and camera, and table (1) illustrates the main features of these sensors. The camera has been calibrated twice; before and after the flight mission using Australis 7 software and the main IOE's of the camera are illustrated in table (2) with standard deviations. The insignificant differences in the obtained IOE's reflect the high-quality level of the camera. The stability of the camera IOE's in all images helps considerably for stable and robust Self Calibration Bundle Block Adjustment (SCBBA) solution, where any changes are reflected on the quality of the image coordinates of the captured objects; and as a consequence, on the Object Space Coordinates (OSC's). The standard deviation values of the obtained IOE's should be used in the SCBBA solution to give the technique more flexibility to adjust the IOE's values and absorb their expected instability.

Figure 1 DJI Mavic 2 PRO drone

Table 1 The main features of DJI Mavic 2 PRO and Hasselblad L1D-20C camera [5]

Hasselblad L1D-20C Camera		DJI Mavic 2 PRO	
Sensor	1” CMOS	Takeoff Weight	907 g
Focal length	Actual: 10.3 mm	Dimensions	214 × 91 × 84 mm
Best ISO value	100	Max speed (no wind)	72 K/h
Shutter speed	8–1/8000 s	Max flight time (no wind)	31 min. (25 K/h)
Still image size	5472×3648	Max flight distance (no wind)	18 Km (50 K/h)
Resolution	4K UHD	RTK possibility	No
Aperture size	f/2.8 – f/11	Max wind speed resistance	29 – 38 K/h
Video Quality	4k (30 & 60 F/s)	Navigation	GPS+GLONASS
Effective pixels	20 MP	Exporting GNSS raw data	No*
Video F/s	30 F/s	Flying in specific tracks	Yes
Pixel size	2.4 micron	Pictures at specific locations	No

*Another low-cost GNSS receiver (u-blox 8) has been fixed on the drone by the research team and connected to the drone GNSS antenna via antenna splitter, which can help for providing GNSS raw data.

Table 2 The main IOE's of Hasselblad L1D-20C camera

Camera IOE (mm)	Before flight mission	After flight mission	Average	Standard deviation mm
Focal length	10.3102	10.3097	10.3099	0.004
Principle point x0	-0.1797	-0.1808	-0.1802	0.002
Principle point y0	0.2593	0.2602	0.2597	0.002

3. Site Description

This paper is based on an actual project, carried out by a surveying and research team at Benghazi University, Civil Engineering Department for the benefit of local oil and gas company. The project includes creating DEM and carrying out topographic surveying for an area 15 km long and 200 m wide. This corridor has been chosen by the exploration team in the company as an initial route for gas and oil pipeline between manifold station and oil and gas refining and processing plant. The site is located in the South of Libya and it is an empty desert area, full of sand dunes, with relative differences in elevations reaching tens of meters. The site, in general, can be divided into 3 main parts; two of which are nearly flat and the differences in elevation increase and decrease unobtrusively reaching nearly 8 m as a maximum, and the third part is topographically complicated, where the differences in elevation fluctuate rapidly, steeply, and significantly, reaching the range of 12 m in some locations. Figure (2) shows the site location on Google Maps, and figure (3) shows the surface nature of different parts in the site.

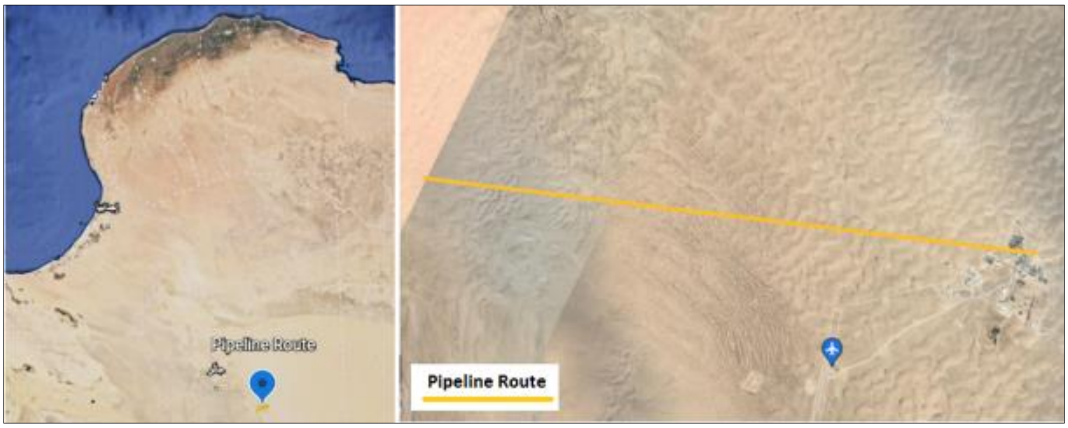

Figure 2 The site location on Google Maps

Figure 3 Examples of site surface nature

4. GNSS Systems & Data Processing

As shown in table 1, the used drone is provided with low-cost GPS+GLONASS receiver with Global Navigation Satellite System (GNSS) circle patch antenna. This receiver is used for navigating the drone in horizontal and vertical direction with accuracy of a few meters in open-sky and multipath-free environments [5]. Circular GNSS patch antenna gathers between the low-cost and the high performance, especially in high altitudes, where only direct over-horizons signals are received and the reflected under-horizon signals are rejected directly [8]. The main disadvantages of patch antennas are the relatively narrow over-horizon receiving angle of signals and the possibility of receiving both left and right hand circular polarization signals [12]. In high altitudes, where the antenna becomes in the highest location comparing to the surrounding buildings, just the direct left hand circular polarization signals can be arrived to the antenna and there is no chance for the reflected right hand circular polarization signals to arrive to the antenna from over-horizon angles [6]. Also, it is not highly-recommended to receive GNSS signals from horizon to horizon, and 10o to 15o cut-off-angle tend to be used for reducing the high effect of ionosphere, troposphere, and interference [8]. The drone GNSS receiver provides real time stand-alone code positioning solution without raw data, and there is no possibility for real time facilities, post-processing and RTK techniques to be applied. Another low-cost GNSS receiver (u-blox 8) has been fixed on the drone by the research team and connected to the drone GNSS antenna via antenna splitter, which can help for providing GNSS raw data.

L1/L2/L5 Leica GS10 GNSS system has been used in this project for fixing GCP's and check points. Static carrier phase Differential GNSS (DGNSS) technique has been used for fixing the selected GCP's and check points along the pipeline route. 30 concrete GCP's and 30 check points have been distribute across the area, one by one every 500 m as required in the scope of work. Precise Point Positioning technique (CSRS-PPP Services) has been used for fixing a base reference point in the area with 6 hours observations. The fixing time of differential GNSS has been used as a function of the distance between the reference point and the rover, where the reference point is located at the beginning of the pipeline route and the distance between the base and the rover increases, reaching 10 km by the end of the route. Time of observation starts from 15 min for the closest point and ends with 45 min for the furthest point. The initial locations of GCP's and check points have been determined from the initial flight mission calculations and fixed using RTK GNSS before getting the final precise coordinates using static DGNSS. The GNSS collected data has been processed using Leica Geo-office, and the final obtained coordinates as well as the standard deviation values have been uploaded to LPS software. Figure (4) shows GCP's and sides of GNSS data collection and stakeout using PPP, DGNSS, and RTK.

Figure 4 Fixing GCP's along the pipeline route using PPP, DGNSS, and RTK

5. Flight Mission: Planning & Execution

As the flight mission calculations in all photogrammetric project are nearly the same and well-known, there will be no need for explaining each step and point, and for such details, see [5]. Table (3) illustrates all the required information for the flight mission planning and calculations. As for the flight mission execution, the flight line track has been uploaded to the drone as KML file with the calculated suitable flight height, and the camera has been set to take 4K UHD video along the flight route using automatic mode. Figure (5) shows the drone flight lines, photos ground coverage, overlapping rate, and GCP's and check points distribution along the route. Figure (6) shows examples of the vertical aerial photos taken by the DJI Mavic 2 PRO drone as a 4K UHD video and extracted as individual frames from a flight height of 350 m above the mean surface height (MSH).

Table 3 Flight mission main calculations & features

Flying mission features	Value	Flying mission features	Value
Area	14860 m * 200 m	Number of flight lines	1
Pixel ground footprint	8 cm	Number of photos/Line	98
Flight height above MSH	350 m	Total number of photos	98
Scale	1:34000	Drone flight speed	10 km/h (2.8 m/s)
Image ground footprint	445 m * 295 m	Flight time	90 min. (3-4 batteries)
Air base	160 m	Camera time interval	Video (4K UHD)
Distance between flying lines	Just one flight line	Number of GCP's & check points	30 & 30
Actual wind speed	6 Km/h	Temperature	23 Co
Whole area covered	15650 m * 295 m	Flight time	11:00 to 13:00 (30 min for changing batteries)

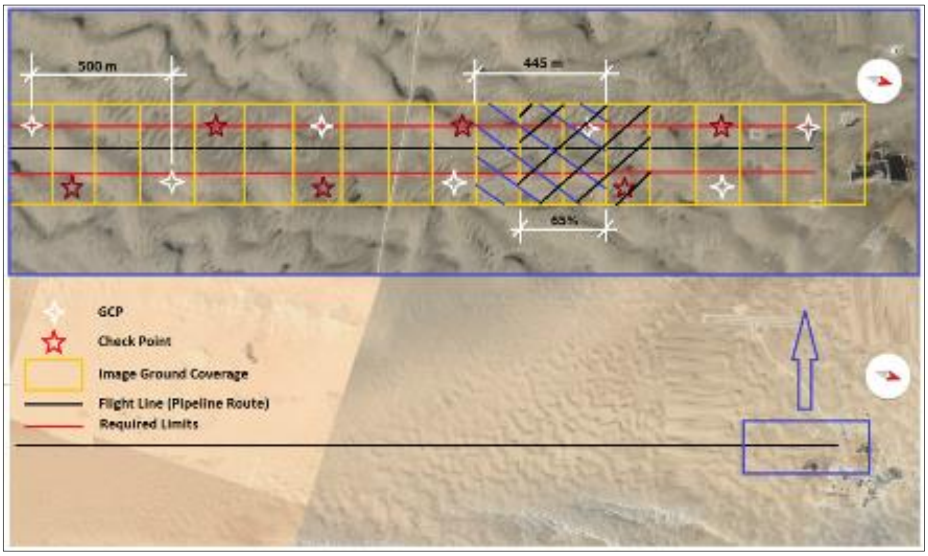

Figure 5 Flight Line, images ground coverage and overlapping, & GCP's and check points distribution

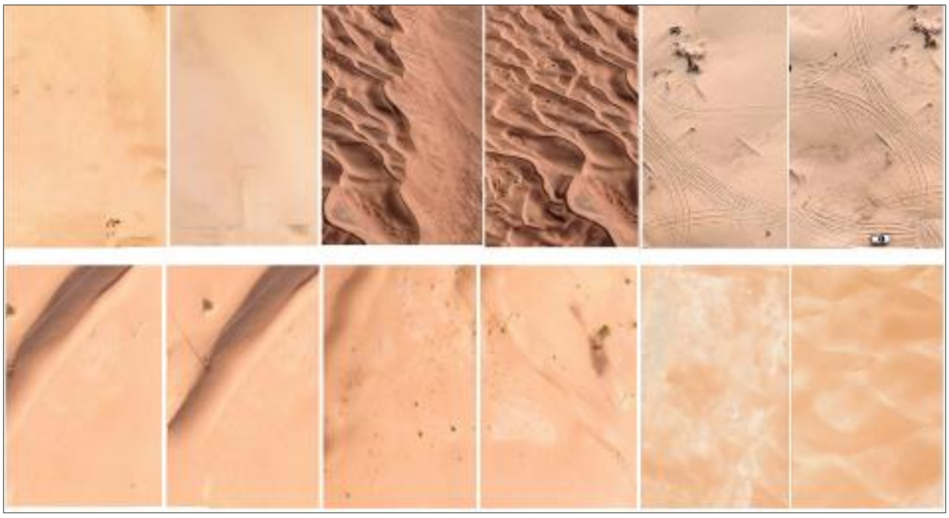

Figure 6 Examples of extracted aerial images, taken as 4K UHD video, by DJI Mavic 2 PRO drone, from 350 m above MSH

6. Processing, Results & Discussion

Table 4 Photogrammetric processing steps

Step	Aim	Inputs	Outputs	Software
1	Extraction frames from 4K UHD video	4K UHD video recorded along the flight line	Individual overlapped UHD images	Matlab Image Tools
	As the flying speed, required overlapping rate, and air base are known, it can be possible to determine the video time, in which the required aerial images have been captured. Then, the video is split into small videos based on the determined times (0.25 s before & 0.25 s after). Finally, the selected small videos are extracted to individual frames. This step reduces the video needed to be extracted to just 1 min instead of 90 min, and reduces the number of extracted frames considerably from 162000 frames to just 1800 frames. The 98 overlapped required images can be detected automatically from the 1800 frames based on the exact calculated capturing time, and checked in terms of overlapping, blurring and tilting.			
2	Gathering all collected data in one SCBBA	Aerial images, camera IOE's, GCP's coordinates, & check points coordinates,	-	LPS
	Standard deviations of IOE's & GCP's coordinates should be uploaded as well for the SCBBA to be more flexible, and the geometry to be more robust.			
3	Matching the images manually using precise tie points	Individual overlapped UHD images	Initially tied aerial images with arbitrary scale	LPS
	This step is important for creating initial relationships between the image coordinates in each overlapped images, which helps of determining the approximate location of any common point of first image on the second, before determining the precise coordinates using correlation techniques.			
4	AIM to create as match tie points as possible	Manually-tied aerial images with arbitrary scale	Automatically-tied aerial images with arbitrary scale	LPS
	In this step, dense tie points are created between the overlapped images for more robust geometry, and these matched points should be filtered manually by vision check or using the image coordinate residuals, which is time-consuming, especially with big number of aerial images.			
5	Filtering AIM tie points automatically	LPS automatic generation tie points	Filtered tie points	Matlap self-developed algorithm
	Epipolar geometry-based filters and 2D transformation-based filters[4, 13, 14, 15, 16] are used for filtering LPS automatic generation tie points. Then, these filtered tie points are uploaded again to LPS.			
6	Bundling all collected data in one SCBBA	Filtered tie points coordinates, IOE's, GCP's & observed check points 3D coordinates, standard deviations	EOP's of each image, computed check points 3D coordinates, and 3D coordinates of tie points	LPS
7	Creating DEM	The required grid size (in this project: 10 m * 10 m)	(10 m * 10 m) 3D ground coordinates	LPS
8	Plotting DEM	(10 m * 10 m) 3D ground coordinates	3D plots	Surfer

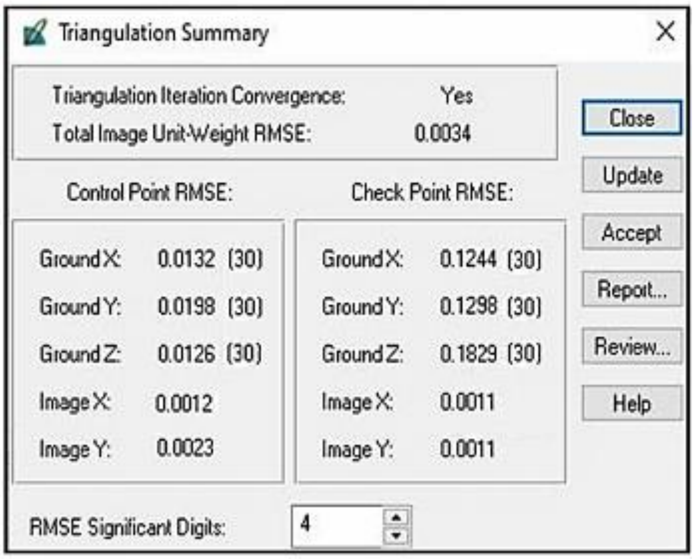

Figure 7 LPS triangulation summary

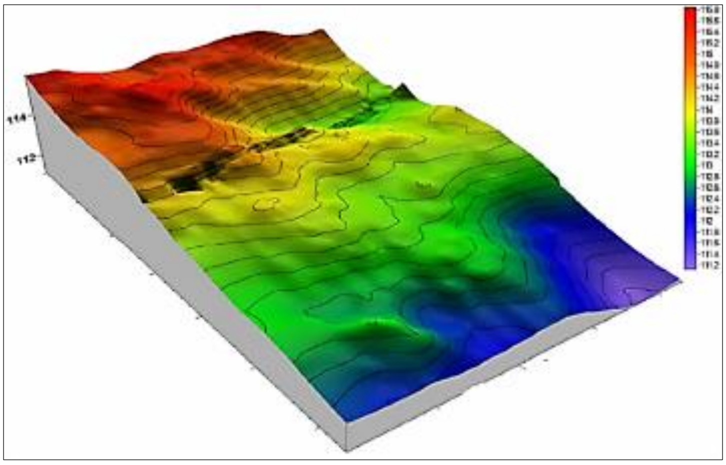

Figure 8 Example of DEM in the first part of the pipeline route

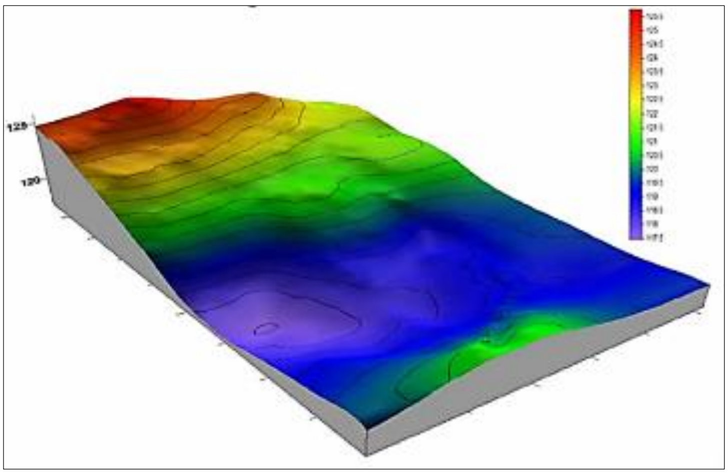

Figure 9 Example of DEM in the mid part of the pipeline route

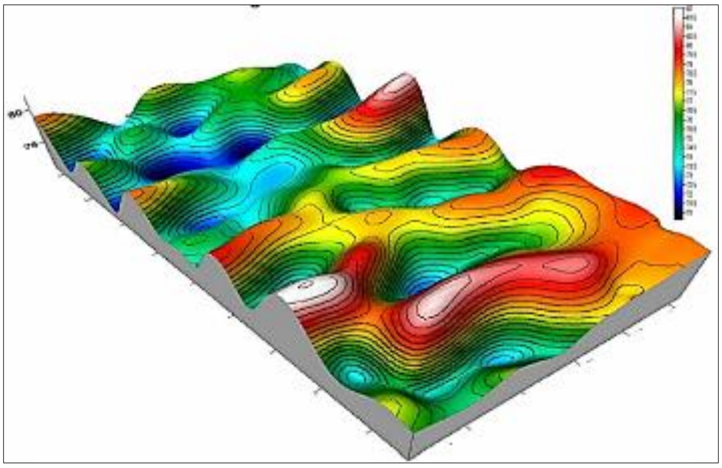

Figure 10 Example of DEM in the last part of the pipeline route

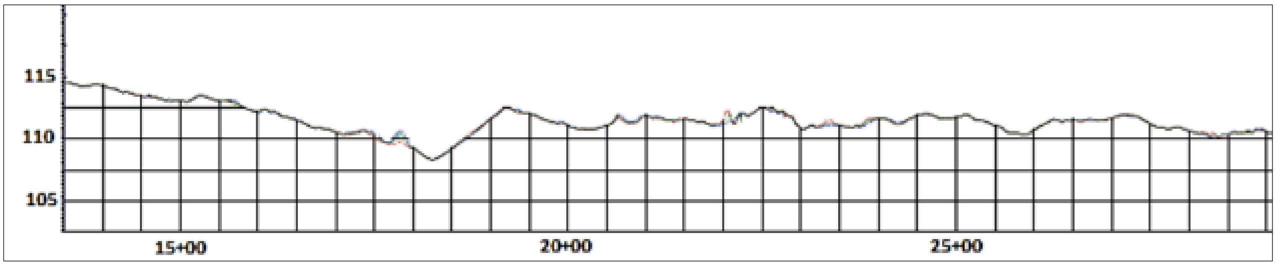

Figure 11 Parts of the selected pipeline route's profile

The whole photogrammetric data processing can be summarized in table 4, which illustrates the main goal of each step, software used, required inputs, expected outputs, and notes. Figure (7) shows LPS results of check points quality. Figures (8), (9), & (10) show 3D DEM's drawn using Surfer software. Figure (11) shows parts of the selected pipeline route profile.

As clear from the LPS triangulation summary shown in figure 7, amateur low-cost drones, such as DJI Mavic 2 PRO, with 20 MP camera can provide 3D topographic surveying data with 3D quality of nearly 1.2 to 2 decimeter using 4K UHD video, pixel ground footprint of 8 cm, and flight height of 350 m. This level of accuracy is suitable for a wide range of engineering applications, such as topographic surveying works for initial planning projects, navigation mapping, engineering urban planning, GIS precise data collection, and earthworks for vast areas. The quality of the generated DEM can be increased by reducing the flight height and using cameras with bigger focal length or with higher resolutions (48 MP, 8K, etc.). The tests show that using 4K UHD video in photogrammetric applications has many advantages, including providing high quality extracted frames similar to that taken individually without blurring, overcoming the complications of determining the capturing stations in site, and the ability of choosing another frames if the selected photos are distorted or blurred. The other advantage of using video is the possibility of changing the overlapping rates throughout the route based on the importance level of the area and the curvature of the route, where the smaller the curvature radius, the bigger overlapping rates should be used. Also, using video allows for creating different DEM's from different groups of sequential overlapped images, which helps for obtaining dense and reliable 3D surfaces. Splitting the video into smaller videos based on the time of capturing the required frames helps for saving time and efforts, where just the small videos are extracted to individual frames and checked for blurring and tilting.

7. Conclusion

In this paper, the possibility of utilizing low-cost amateur drones with 4K UHD video for topographic surveying works and creating DEM's has been investigated. DJI Mavic 2 PRO drone has been used for covering an expected gas & oil pipeline route in the South of Libya with length of nearly 15 km and width of 200 m. The quality of the results has been evaluated using a significant number of well-distributed check points. High precise well-distributed 30 GCP's have been used for stable and robust geometry. The Hasselblad L1D-20C 20 MP camera used in this paper has been calibrated before and after carrying out the flight mission for reliable IOE's. For saving time and efforts, the main video has been split into smaller videos using Matlab image tools and based on the capturing time of the required frames. All images has been processed in LPS software and the automatically generated tie points have been filtered using epipolar geometry-based filters and 2D transformation-based filters. Tests show that 3D topographic surveying maps with 3D quality of nearly 1.2 to 2 decimeter can be obtained using low-cost drone with 4K UHD video, pixel ground footprint of 8 cm, and flight height of 350 m. This quality level is suitable for many engineering applications, such as topographic mapping works for initial planning projects, navigation, urban planning, GIS data collection, and inventory of earth works materials. The obtained quality of the generated DEM is a function of the flight height and camera quality, IOE's, and resolution. Using 4K UHD video for photogrammetric applications helps to provide high quality extracted frames, similar to that captured separately, especially with suitable flight speed, ISO sensitivity, shatter speed, and aperture size. Using video helps also for overcoming the difficulties of determining the suitable capturing time and location in the site. The other advantage is the ability of taking alternative frames if the selected images are corrupted. The opportunity of chaining the overlapping rates throughout the route is another important advantage of using video, especially in case of curvy routes. Using different groups of overlapped images for the same route helps for creating different DEM's for the same surface, which can be used for more precise and dense topographic surveying works. As further works, it is suggested to evaluate cameras and videos with different resolution levels, such as 48 MP, 108 MP & (6K, 8K, 10K). The integrating of low-cost GPS with aerial image-based navigation is another innovative idea can be recommended for reducing the high need of GCP's.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors hereby declare that there is no conflict of interest among them or with any person/organization.

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