Application of A Drone Camera in Detecting Road Surface Cracks: A UAE Testing Case Study

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This research aims to introduce DJI Phantom 4 Pro, and its process of calibration and image processing. To get accurate aerial photos, a camera calibration process has been applied to find the true parameters (e.g., focal length, format size, principal point, and lens distortion) of the camera that took the photographs. Results from the point of view of variance factor confirmed the reliability of this camera for photogrammetric work. This study also calculates the 3D coordinates of unknown points on the ground and added Photogrammetric Derivatives DEM and accurate Digital Orthophotos to check the road condition. It is difficult to precisely identify them using publicly accessible standard satellite imagery (including the three multispectral bands (G, R, NIR) with resolutions of 20 meters). Agisoft software has been used for image analysis and for accuracy checking to detect street cracks to provide recommendations and guidance to the related planning entity for maintenance. Captured aerial crack images were processed using Agisoft software, from which orthophotos were produced and potential cracks identified. Moreover, the study aims to achieve optimal quality in a road 3D model using MMS and to determine the number of control points or sections needed to create an accurate 3D model of the road to be used as initial data information in the rehabilitation process by detecting the cracks in the roads.

Keywords: Orth Mosaic, Street Crack Detection, Drone Technology, Aerial Image, MMS

Introduction

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand et. al. 2008). In photogrammetry, the general solution for all unknowns is carried out using an optimizing procedure called block bundle adjustment. All bundles of rays (images) from the camera to ground points are reconstructed to fit each other on the ground. This procedure requires different input information about all parameters that appear in the collinearity equations.

With an increasing advancement in the field of drone research, more sophisticated and cost-effective automated flight systems have been introduced, which are cheaper and portable. Affordable universal drones have the potential to effectively increase efficiency in several industries. PricewaterhouseCoopers (PwC) predicts that drone solutions have a high possibility for reducing the \$127 billion in current business services and labor costs across multiple industries (Walker 2017). They believe that drones could have a greater influence on infrastructure, agriculture, and transportation. In addition to their application in policy reform and decision-making, commercial drones are currently making a huge impact in industries that utilize them to quickly and cheaply gather localized visual information. These industries include agriculture, geography, construction, infrastructure, and inventory management (Walker 2017). Inspection of infrastructure is the evaluation of the physical conditions of civil structures such as buildings, highways, bridges, sewer and water pipelines (Fenves 1984). The vision-based process involves detection of any visual changes such as cracks, leakage and corrosion on these structures (Stent et al. 2016).

This study thus provides a new approach to detecting road cracks by applying drone digital photogrammetry to consistently locate pavement fractures. Drone cameras must be calibrated and orientation parameters computed before using such output images. The final models will be compared against satellite pictures using different camera settings. The camera calibration procedure will be explained, followed by an example case study to model real life roads.

Literature Review

Aerial Image Analysis to Detect Cracks for Decision-Making

To ensure that structures are sound and durable, regular monitoring of the surface and internal materials is crucial. Manual contact measurements (e.g., crack-scale) were traditionally used to detect cracks in structures (Chen et al. 2006). However, they were complex, time-consuming and showed inconsistent results. Thus, due to technological advancement, several aerial (drones) and non-aerial automation systems and techniques have been introduced (Kim et al. 2015). Introduction of new technology rendered the crack analysis in roads cheaper, reliable and efficient, and equally important, such technology can overcome other limitations of conventional visual inspection methods.

Using Non-aerial Automatic Systems to Detect Cracks

Semi-automatic measuring system that can extract images of cracks on the surface of concrete from multitemporal images was studied by Chen et al. (2006), where they estimated and analyzed the relationship between the expansion of the concrete and crack width using both the automatic extraction and the manual measurement method. A high-resolution scanner (AGFA DUOSCAN T2500) of about 10.2 μm was used and the results showed that the consistency of crack widths between the two methods could reach 0.05 mm. A similar study on cracks identification with respect to length and width was also reported by Kim et al. (2017) using a more advanced hybrid technology, utilizing a camera LS-20150 with a resolution of 2592 pixels × 1944 pixels. The hybrid image binarization processed the extracted information to measure the crack width correctly while reducing the loss of the crack length information. The study concludes that the system has demonstrated the capability to measure cracks thicker than 0.1 mm with the maximum length estimated error of 7.3%.

A new automatic (laser imaging) system using an LRIS 4K camera with a resolution of 4096 × 2048 pixels to identify cracks in images taken during pavement surveys was introduced by Oliveira and Correia (2010). The study used an approach based on image smoothing; automatic segmentation by thresholding; a new procedure to link the resulting binary regions and to decide whether to label them as cracks. The system starts with texture smoothing of pavements, which is useful to distinguish between pavement roughness and cracks. For this purpose an anisotropic diffusion filtering is used which is followed by a frequency curve that helps to model the histogram for pixels intensities below a certain value. Finally, crack identification results were presented.

Over the years, structural crack identification using drones has significantly advanced across many areas. Conventionally, road inventory was done by field inspection. Now it is being replaced by examining mobile mapping system images. In terms of precision, the development phase of automatic crack detection has been advanced with the introduction of mobile mapping, deep neural learning or Deep Neural Network (DNN), and deep architecture of convolutional neural networks (CNNs) methods (Gopalakrishnan et al., 2017).

A study in Sweden by Some (2016) employed a step-by-step pixel-based image intensity analysis, and deep machine learning to test for automatic crack detection from mobile mapping images by applying these two distinct methods. The author examined the performance of the methods and compared their group precision using an LMS511 PRO laser scanner camera with image resolution of 2448 × 2048 pixels. The best-acquired precision with the trained deep learning model was 98%.

This is 3% better than with the other method and it suggests that the deep learning is the most appropriate for the application (Some 2016). Similarly, in Turkey Ersoz et al. (2017) recently combined conventional machine learning with newly introduced image processing algorithms to check for detection of cracks on rigid pavement surfaces and their classification using a DJI Inspire 1 Quadcopter with a resolution of 4000 × 3000 pixels.

Using Aerial Automatic Systems (Drones or UAVs) to Identify Cracks in Roads

With technology development in cameras, the visual examination system using drones is gaining substantial attention across multiple industries, including geography, agriculture and the field of civil engineering. Ellenberg et al. (2014) examined infrastructural evaluation using Unmanned Aerial Vehicles (UAVs) commonly known as drones, with a focus on masonry crack detection. The authors examined several algorithms to identify cracks, such as edge detection, the percolation approach.

In the last few years, numerous studies have utilized drones for surface crack detection. Ersoz et al. (2017) suggested a UAV-based pavement crack identification system for monitoring the existing conditions of rigid pavements. A similar study in South Korea by Na and Baek (2016) employed a vibration-based non-destructive evaluation (NDE) method to identify small damages which are hard to recognize and internal damages such as thickness reduction. Their study, which used a SYMAX5HW drone, suggested a novel idea of employing a drone for structural health monitoring (SHM) of civil infrastructures. This is a concept which overcomes the existing constraints of using a drone together with image processing and a visual inspection method. Thus, UAVs have the potential to significantly change the way infrastructure evaluation will be conducted in the future (Ellenberg et al. 2014). These findings were replicated by Phung et al. (2017), who built an automatic crack detection system for infrastructure monitoring. They included two stages, data collection using drones and crack detection using histogram analysis. Many tests conducted showed all cracks detected in real time.

For safety concerns and massive disaster prevention, a breakthrough (hybrid) technology in the inspection and investigation of the structure was proposed by Kim et al. (2015) in the Republic of Korea. The researchers developed the crack detecting system using UAV and digital image processing techniques - a structure inspection system to detect cracks in the structure. This overcomes the limitations of visual inspection and inaccessibility of areas during field inspections. Combining the application of UAV and the digital image processing technique makes it possible to detect damage and cracks on the surface facilities by acquiring the image of the structure and analyzing it (Kim et al. 2 015). The morphology method based on morphological hydraulics was used to conduct the image analysis for crack identification. Another study conducted in South Korea by Kim et al. (2017) presented a similar crack discovery strategy that combines hybrid image processing with UAV technology. The system is equipped with a camera, supersonic displacement sensor, and a Wi-Fi module, which allows it to provide both the image of cracks and the associated working distance from a mark structure on demand.

Furthermore, Convolutional Neural Networks (CNNs) are deep neural networks which are applied to analyze visual imagery. This has been used by Cha and Choi (2017) to develop a classifier to detect concrete cracks. The CNN is a vision-based method and its main advantage is that it can detect concrete cracks with no removal and calculation of defect features as opposed to conventional methods. The CNN method does not require the combination of image processing techniques (IPTs). It is trained on 40 K images of 256 × 256-pixel resolutions and hence can capture detail with almost 98% precision (Cha and Choi 2017). Numerous comparative studies were conducted by the authors to evaluate the performance of the CNN and their results indicated that the method had better performance and can detect concrete cracks in practical situations.

The application of new technology like drones could minimize or replace the use of high-cost equipment and the utilization of inefficient methods for visual inspection work with safety. The above literature report has highlighted various drone applications in crack identification for better urban planning, policies, and decision-making. However, further research on the limitations or factors that influence the precision of photogrammetry may be required.

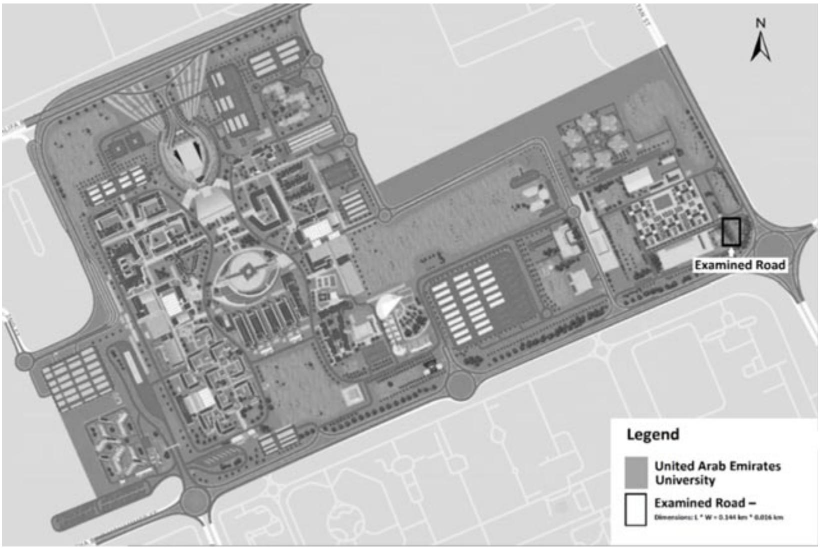
The main objective of the present project is to utilize close-range digital photogrammetry to design an easy and accurate solution for pavement cracks identification. In this project, photographs taken by common drone stream cameras will be used to model real life objects. To be able to use such photographs, cameras must first be calibrated and the interior orientation parameters determined. A variety of camera settings will be used, and the final models will be compared with satellite images.

Research Methodology and Study Area

Crack Identification using Drone – Case study area

A crack is a breakage and splitting in the road surface that appears due to environmental forces (Wei and Simmons, 1973). In other words, cracks are damage on the surface which depending on the magnitude of its severity could affect traffic safety. Therefore, it is necessary to measure the crack dimension in order to know the crack influence on vehicles. It was part of the study's approach to detect cracks on the UAE University campus (Figure 1). The images were taken using a DJI Phantom 4 Pro Drone on 27 May 2018. The surveyed road has a width of 0.016 km and length of 0.144 km. This study demonstrates the usefulness of using drones for crack identification over satellite images.

FIGURE 1
Illustration of study area in United Arab Emirates University



Field Visits and Drone Flight Tests

It takes several steps from selection to testing if all its specifications are working correctly. The DJI Phantom 4 Pro (Figure 2) is the drone type used in this study. It is equipped with a 1-inch 20 MP camera; the Phantom 4 Pro is capable of shooting 4K 60fps video and 14fps Burst Mode stills. The battery has a max flight time of 30 minutes, and a maximum transmission range of 7 km. This drone was first upgraded before testing. The firmware of the drone was downloaded from the website, placed in a memory card and inserted into the drone to update its system. The upgrading process was performed in the lab, and the flight test took place at the surveying network field. This was to test if the drone specifications like image quality/resolution, flight altitude (10m to 15m above ground level), motion directions (left, right, backward, forward etc.) were all functioning well and are up to standard.

FIGURE 2
DJI Phantom 4 Pro equipped with high-definition camera used for visual inspection in this research

Camera Calibration

First, the drone cameras (DJI Phantom 4 Pro) were calibrated, and the interior orientation parameters (IOP) were calculated, to set and maintain the precision and accuracy of the drone. The camera calibration was conducted at the E5 Laboratory at UAE University. The numerical measures of the interior orientation parameters of the camera were determined (Figure 3). It was also ensured that the interior orientations correspond with the principal distance (c), location of the principal point (xp, yp), and image coordinate corrections that compensate for various deviations from the assumed perspective geometry, which together are known as the IOP of the camera. A bundle adjustment with self-calibration was the technique used to determine the IOP.

Phantom 4 Camera Calibration Procedure

The existing wide-format calibration field was used to calibrate the new drone camera. The Calibration process was conducted in the following steps as illustrated in Figure 4:

1 Start dataset acquisition for the camera calibration phase. This includes field measurements on the test field in addition to multiple photographs in predesigned configurations necessary for successful calibration (Figure 5).
2 Start the semi-automatic and manual data measurement from the acquired images for each dataset utilizing AgisoftPhotoScan software.

3 Prepare calibration data input files for processing using Bundle Adjustment software.
4 Analyze and present the results of camera calibration.

FIGURE 3
Camera calibration using physical board in UAE University Laboratory

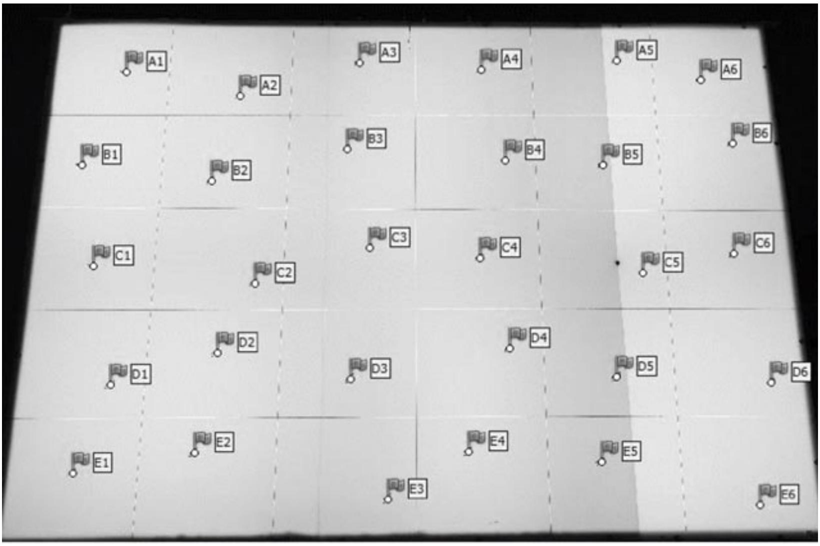


FIGURE 4
Camera calibration steps

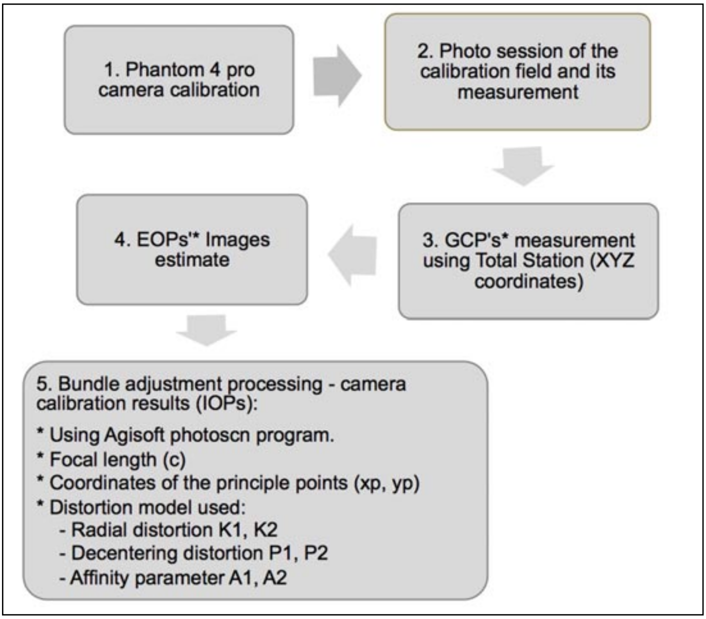
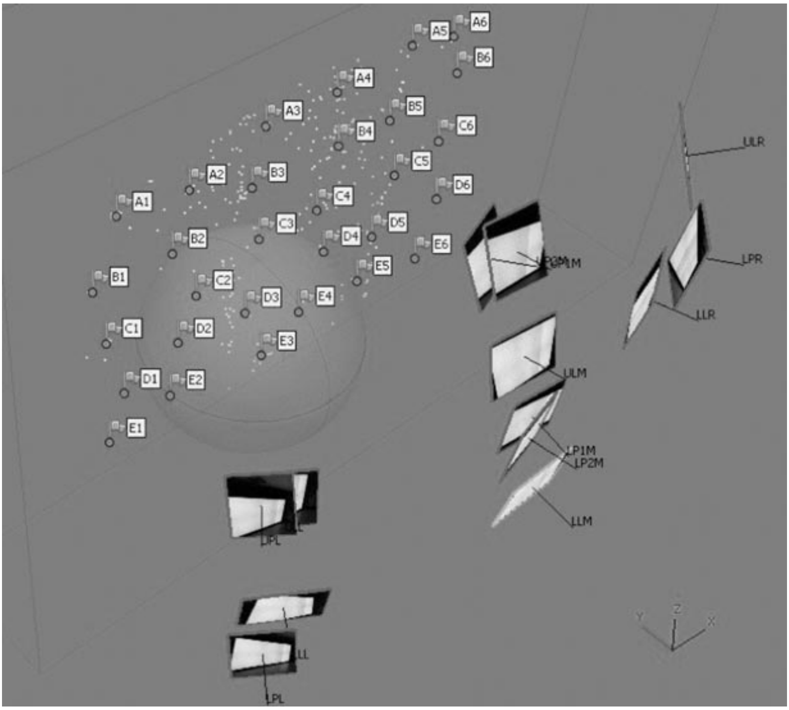


FIGURE 5
Perspective view showing the location of exposure stations, camera orientation and GCPs using Agisoft software



Camera Calibration Results

After applying the camera calibration steps, the following error results were determined (Tables 1-4):

TABLE 1
Average camera location error

Image count	X error (mm)	Y error (mm)	Z error (mm)	XY error (mm)	Tot. error (mm)
13	2.56E-01	2.90E-01	4.80E-01	3.87E-01	6.16E-01

TABLE 2
Average camera rotation error

Omega error (°)	Phi error (°)	Kappa error (°)	Total error (°)
1.29E-02	6.07E-03	4.54E-03	1.50E-02

TABLE 3
Control points RMSE

Count	X error (mm)	Y error (mm)	Z error (mm)	XY error (mm)	Total (mm)
3.00E+01	2.19E-02	6.03E-02	2.73E-02	6.42E-02	6.97E-02

TABLE 4
Calibration Results

	Value (Pixel)	Error (Pixel)	Error (mm)
F	3.67E+03	6.30E-01	1.51E-03
Cx	5.88E+00	6.10E-01	1.46E-03
Cy	2.02E+01	6.10E-01	1.46E-03
K1	-8.63E-04	4.70E-04	1.128E-06
K2	2.52E-03	6.30E-04	1.512E-06
P1	-5.81E-04	6.20E-05	1.488E-07
P2	1.02E-03	5.70E-05	1.368E-07

The DJI Phantom 4 Pro camera could be successfully calibrated with consistent and excellent results. This drone camera can be relied upon for photogrammetric mapping. The camera results from the variance factor point of view were as expected and confirm the reliability of this camera for photogrammetric work.

Data Roadway Crack Images Collection Using the Drone

The data (road crack images) collection phase employs a manual method to identify road cracks in images captured during roadway survey. A crack is a breakage and splitting in the road surface that appears due to environmental forces. In other words, cracks are damage on the surface which as per the magnitude of severity could affect traffic safety. Therefore, it is necessary to measure the crack dimension in order to know the potential crack influence on vehicles. The survey was carried out at UAE University on 27 May 2018. The road surveyed and the procedures include three stages:

1 Marking Ground Control Points (GCPs): First, we arranged and labeled the GCPs over our survey area of interest. We nailed about five GCPs into the ground, then marked the center of each point with black color and numbered them from left to right to make them visible enough from a far distance.
2 Field measuration of GCPs using a precise total station: The measurement was performed to determine and calculate the accuracy of the positions/coordinates of the aerial crack photos to be collected in the coordinate system. GCPs were well positioned and marked to make them easily visible on aerial images. Due to the nature of the survey area, a few GCPs (about 5) were used to obtain the desired precision (Figure 6).
3 Images capturing using the drone (DJI Phantom 4 Pro): This step involves flying the drone over road cracks at a selected altitude of 10 meters to take crack images. The images collected during the flight were guided by ground control points (GCPs) shown in Figure 7,

which all have marks on them for easy aerial photographs visibility and accurate drone mapping. The drone flight lasted for 10 minutes.

FIGURE 6
Total Station TS16i for the ground support of GCPs

In this research, three cases were explored depending on the availability of reference points or adding the results of the camera calibration or both, which are of great importance in obtaining high accuracy and reducing errors resulting from the manufacture of the camera. The three cases are detailed as follows:

Case 1: includes the addition of 6 reference points and the results of camera calibration. This approach is the best solution to reduce all errors, but it is difficult to implement due to the need to measure the reference points using GPS, which requires clearing the streets of vehicles to install and measure the points.

Case 2: only the results of the calibration were added, as it was found that the results are acceptable on the road crack level. Which can be used to analyze the road cracks to study the medium and only large cracks.

Case 3: no reference points or calibration results were added, as this caused a large dispersion of the readings with a countless error rate.

Experiment and Results

Photogrammetry Image Processing

Image processing is a technique to conduct some operations on an image. It is performed to enhance the image or to extract some valuable information from it. It is a kind of signal processing which has an image as input (Figure 8) and its output as a report that is based on image analysis or a modified image/feature (Figure 9).

FIGURE 7
Point cloud showing distribution of GCPs used in the drone flight process
(Average Length × Width= 0.144 km × 0.016 km)

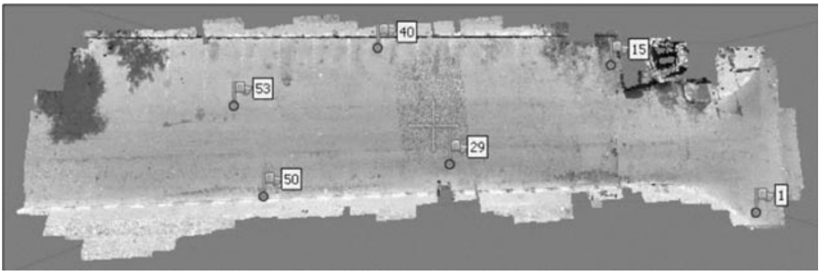


FIGURE 8
Outputs (orthophotos) of road cracks image processing
(Average Length × Width= 0.144 km × 0.016 km)

The road crack images captured by the drone were processed at the UAEU Laboratory, using Agisoft software, and it includes the following steps: a) transforming the earth-centered, earth-fixed (ECEF) coordinate system to east north up (ENU) coordinate system; b) adding imported images to points, making sure each image corresponds with its point; c) attaching camera calibration results to Agisoft program for more accuracy; and d) building the orthomosaic using the software and thereafter exporting the orthophotos. Shown below are orthophoto results deriving from road crack image processing taken by the drone.

The resolution obtained from the three cases has the same orthomosaic image (Figure 8), because their resolution was the same. However, the precision in the three cases differed. Table 5 shows the digital caliper measurements of the 5 road cracks, whereas Table 6 shows the manually measured cracks that were compared to the cracks in the three cases.

TABLE 5
Specifications of the three photogrammetry cases studied

Photogrammetry Cases	GCP	Camera calibration
Case 1	yes	yes
Case 2	no	yes
Case 3	no	no

TABLE 6
Three case studies and 5 identified cracks

Crack	Crack Width				DC-Case 1		DC-Case 2		DC-Case 3	
	Digital Calliper (DC)	Case 1	Case 2	Case 3	Difference	% Error	Difference	% Error	Difference	% Error
1	0.05178	0.05177	0.04939	0.01364	0.00001	0.02%	0.002387	4.61%	0.038143	73.66%
2	0.00684	0.00669	0.00632	0.00049	0.00015	2.25%	0.000524	7.66%	0.006352	92.87%
3	0.03072	0.03079	0.02928	0.00798	-0.00007	-0.22%	0.001436	4.67%	0.022741	74.03%
4	0.0037	0.00367	0.00338	0.00046	0.00003	0.84%	0.000319	8.62%	0.003241	87.59%
5	0.03236	0.03239	0.02988	0.00781	-0.00003	-0.09%	0.00248	7.66%	0.024555	75.88%
					AVG.	0.56%		6.65%		80.81%

The results showed that Case 1 has the least amount error of 0.56%, followed by Case 2 (6.65%) and Case 3 with an error of 80.81%. These results showed that it is better to use Ground Control Points with Camera Calibration for obtaining results with the least errors.

Mobile Mapping Systems (MMS) Processing

The created road surface model by MMS permits performing many analyses related to the road condition, such as road surface damage (ruts, cracks, and potholes) that will be useful to be integrated in the BIM process for maintenance and road rehabilitation. Point cloud presents damage on the road surface and the field verification using road images and surface damage analysis.

Amman-Aqaba Desert Highway Rehabilitation

The case study is a part of the Highway (Amman-Aqaba Desert Highway) road project of reconstruction and rehabilitation at the end of 2017. The project involves a complete reconstruction of 220km of that road. Road surface damage analysis is indicated in Figure 9, which presents the damage on the road surface.

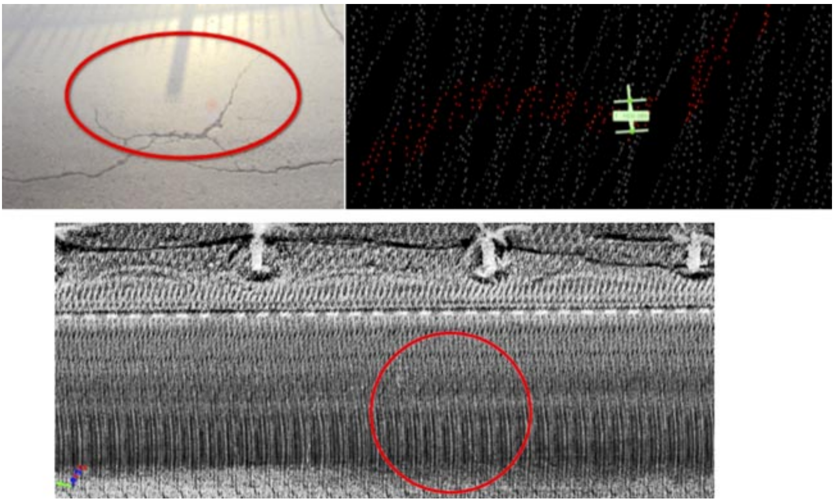
Portugal Road Rehabilitation – 2018

The experiment in this case is to detect the damage value of the town road by using MMS technology, because it is the most effective way to make the best decisions in the rehabilitation process.

As we can see in the following Figures 10 and 11, we can detect the cracks in the road more accurately by using the dense point cloud taken from the Faro laser scanning device.

FIGURE 9
Crack Detection from Mobile Laser Scanning Point Clouds and images

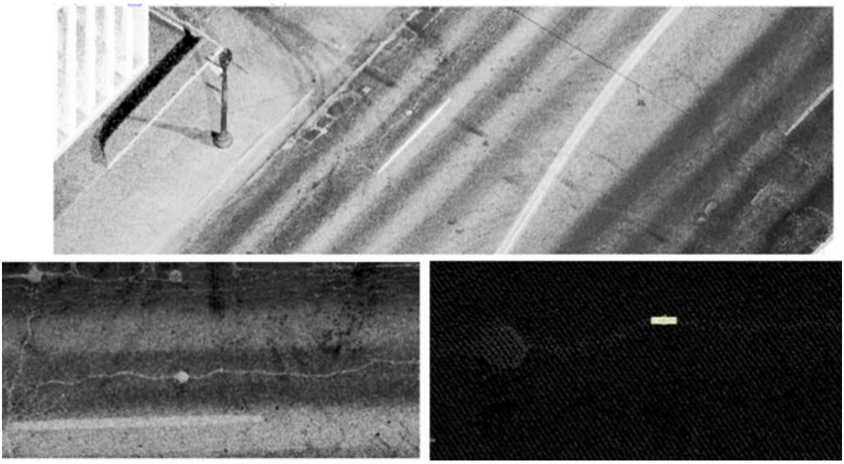
FIGURE 10
Location1: crack 1 detection using point cloud and images



MMS is very effective for creating a 3D model for the roads to be used in several projects and research. However, there are important considerations to be kept in mind during the surveying and the data preprocessing:

1 Strip matching and adjustment is an essential step in point cloud data processing and it should be done for different missions and different surveying directions.
2 To get a reliable precise 3D model to be used in digital transformation processing, the point cloud should be adjusted and corrected with known cross-section points.

FIGURE 11
Location2: crack1 detection using point cloud



3 Processing of GPS/INS data to create an MMS trajectory should be done based on the nearest GPS reference station. To prevent corruption in ambiguity resolution, avoid the processing of data for baselines more than 15km distance between the MMS car and GPS reference station.
4 Scan to model in the road project is efficient and accurate to create the initial 3D model to be used in the rehabilitation process.
5 Table 7 shows the dimensions of the cracks, which include the length of the cross-section as well as the depth, using the Maverick Mobile Mapping System, which can collect up to 700 000 data points per second. MMS also provides the car's speed of 60 km/h, implying that it can provide sufficient information for road crack extraction.

TABLE 7
Two case studies and 2 identified cracks

Crack Dimension	Location 1 - Crack1	Location 2 - Crack1
Depth	2 cm	1 cm
Cross Length	8.9 cm	7.3 cm

Discussion and Comparison of Drone Images with Satellite Images and MMS

The three cases showed that Case 1 has the lowest error with an average for 5 cracks as 0.56% (Figure 13). However, Case 1 required Ground Control Points (GCPs), which becomes impractical in most cases. Case 2 is more precise and independent, as it relies only on camera calibration and only has an error of 6.65%. Thus, Case 2 is more practical in the identification of road cracks in roads using a drone.

In this study, different steps for the calibration of DJI Phantom 4 Pro drone are explained. The error margins in the calibration stage were determined followed by the corrections. The camera 1-inch 20 MP camera; the Phantom 4 Pro is capable of shooting 4K 60 fps video and 14 fps Burst Mode stills. The battery has a max flight time of 30 minutes, and a maximum transmission range of 4.1 mi (7 km). The drone flew over 10 m above ground level.

FIGURE 12
Error percentage in three cases

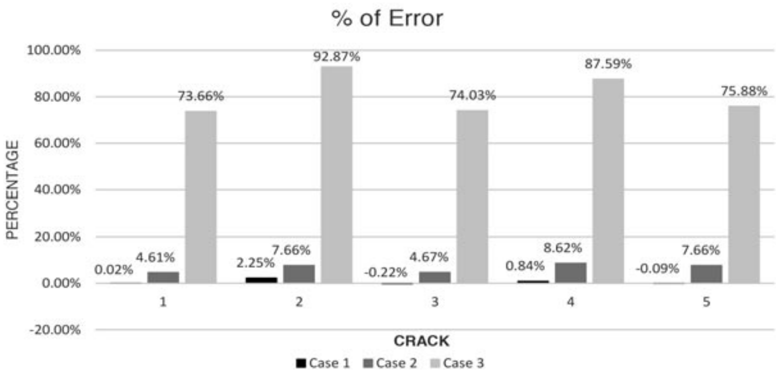
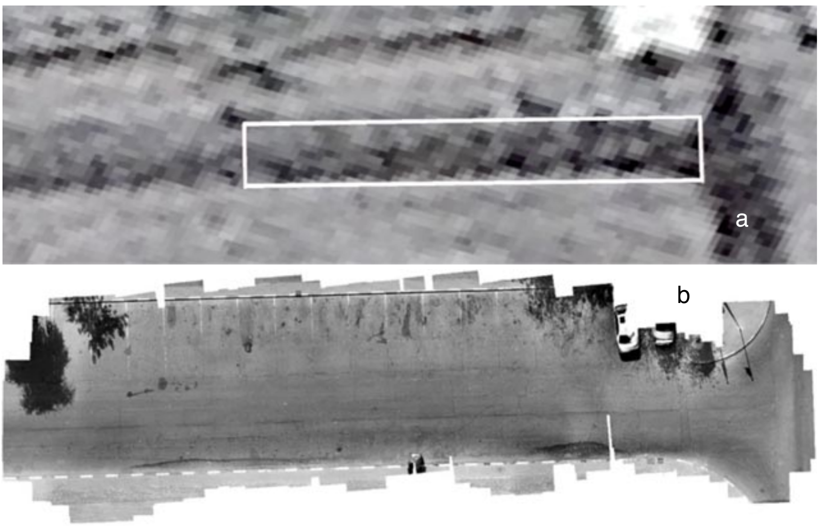


FIGURE 13
Comparison of study area images from (a) DubaiSat-2 satellite and (b) Phantom 4 pro drone



The comparison of drones and Mohamad Bin Rashed Space Center (MBRSC) DubaiSat-2 satellite imagery in Figure 14 shows that these drones are more effective for in-depth study of cracks in streets. The type of cracks and its intensity can easily be identified. The image spatial resolution of Mohamad Bin Rashed Space Center satellite is 1 meter whereas the resolution for DJI Phantom 4 Pro is 1.28 mm. Thus, investigation at micro level. such as cracks, can be easily conducted using drone images.

There are advantages and disadvantages for using drones as compared to the satellite images. Drones can carry different sensing instruments which include visible light, near infrared, shortwave infrared, radar and lidar sensors. Thus, the images obtained are clearer in vision and can be processed easily for analysis. However, the disadvantages are the limited area coverage and ground support sites for operation and maintenance.

The satellite images experience essentially zero vibration, do not require ground support, can image on a large scale over different timescales and are unaffected by weather.

Conclusion

Photogrammetry technology is an ineffective way for finding crack depth because it relies on light reflection that is not available inside the road cracks. However, it is considered very accurate in measuring the length of the cross-section of the cracks, and its accuracy is up to 1 mm. The advantage of laser technology is that it relies on the ability to distinguish during the absence of light. Lasers are very expensive compared to unmanned aircraft.

DJI Phantom 4 Pro is an effective drone that can be used for road crack study in the field of civil engineering. This study shows different steps in the calibration of a drone, using Agisoftphotoscan software. The DJI Phantom 4 Pro camera could be successfully calibrated with consistent and excellent results. This drone cameras can be relied upon for photogrammetric mapping. The camera results from the variance factor point of view were as expected and confirm the reliability of this camera for photogrammetric work. It was applied to two roads inside UAE University to obtain road crack images. The locations of the images taken from drones were also compared with field measurement of GCP's using a precise total station. Image processing techniques were applied to these images in Agisoft to convert these raw images into modified images that are more visible and accurate for study. The resulting orthomosaic images were clearer and more identifiable for the study. Thus, application of drones in crack identification is helpful to obtain a clear image and the dimensions of the cracks. These drones can be applied effectively to urban roads to study the cracks on already existing roads.

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