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Detecting abuses in archaeological areas using k-mean clustering analysis and UAVs/drones data

Key words: unmanned aerial vehicles, k-mean clustering, unsupervised classification, Pix4D, remote sensing, archaeological survey

Introduction

In recent years, new technologies in archaeology have emerged to get reliable data easily and at a lower cost. Unmanned aerial vehicles (UAVs) or drones have become advanced technological devices that archaeologists use and aim to add to their survey and gravure kits. Drones used for 3D documentation and analysis of landmarks and historical structures, aerial mapping, and forest archaeological analysis. Drones used now instead of the conventional field walking approach known as the pedestrian survey, which was historically used by archaeologists and archaeology students (Hill, Laugier & Casana, 2020). While satellite imagery offers wider coverage for any surveys (Bi, 2020), but at considerable expense and with little spatial precision compared to the cost and precision of drones' spatial discrimination, which flies at a relatively low altitude, providing a precise view of the archaeological region being surveyed. Satellite images vary in their spatial resolution and by the satellite used, which means they can cover an area of one kilometer per pixel in the image, or hundreds of meters, or at best tens of meters per pixel. This little precision has limited applications to uncover archaeologist's tiny archaeological features. Though these satellite images can be obtained free of charge, such as the satellite launched by the European Space Agency called Sentinel, which provides excellent spectral bands with a spatial accuracy of 10 m per pixel, it is not considered effective in the study of often small monuments and archaeological areas (Noor, Abdullah & Hashim, 2018). In addition to restrictions on the use of satellites such as the large height of the satellites and the distance between the satellites and the earth, this means that the emission signal entering the sensor is affected by water vapor, the ozone layer, and clouds that adversely affect the quality and accuracy of the data (Agudo, Pajas, Pérez-Cabello, Redón & Lebrón, 2018). Therefore, drones images are the solution and providing archaeologists and students with very high capabilities, as they provide us with photos with a spatial resolution of up to a few centimeters per pixel and depending on the visual characteristics of the various sensors that these drones can bear. Furthermore, these drones offer a solution to the cloud problem and other weather effects induced by the satellite altitude on data quality, since drones fly at very low altitudes of 100 m or fewer. Besides the low cost of these planes, it has the possibility to repeat the survey process to record a higher time accuracy that reaches multiple times daily. However, it is still an up-to-date technology and as many formalities and security regulations have applied to its use, policy limitations on its use are growing (Brooke & Clutterbuck, 2019).

Unsupervised machine learning and classification techniques have been used in archaeological research (Jaimala & Sarita, 2020). In this research, the proposed approach uses a k-means clustering technique for image analysis which has been used broadly in image analysis. This unsupervised clustering does not use labels that define the classes. There are no information presents regarding the category or class label which differentiates the unsupervised classification concept. Clustering is a technique that analysis data objects then split them into a number of subgroups based on the information found in data that describes the objects and relationships among them (Aggarwal & Aggarwal, 2012). k-Means algorithm firstly select k-objects as initial cluster centers, then calculate the distance between each cluster center and each object, and assign it to the nearest cluster, update the averages of all clusters, repeat this process until the criterion function converged (Vora & Oza, 2013).

The general objective of this research is to demonstrate the feasibility of using drones to maintain and track important archaeological sites that appeared to have been largely neglected and affected by thieves and looting in Iraq, as well as civil excesses and the random construction that occurs on the archaeological areas, particularly after 2003. An aerial surveillance system, which consists of modern DJI Phantom 4 drones in combination with the advanced Pix4D program, was used. The Pix4D's capabilities to analyze captured images, conduct processing operations, and generating image mosaics have been illustrated. k-Mean clustering algorithm was used to classify the resulting data to clarify the morphological changes and updates that happen in the archaeological sites. Expecting that this new system will be used and adapted by other local archaeological teams to protect our cultural heritage from neglect, damage, and theft.

Material and methods

Study area and devices used

The archaeological region of Nineveh was chosen as a case study, positioned in Mosul's city center and on the eastern side of the river Tigris (Fig. 1), near the University of Mosul, was chosen for its historical importance and be-

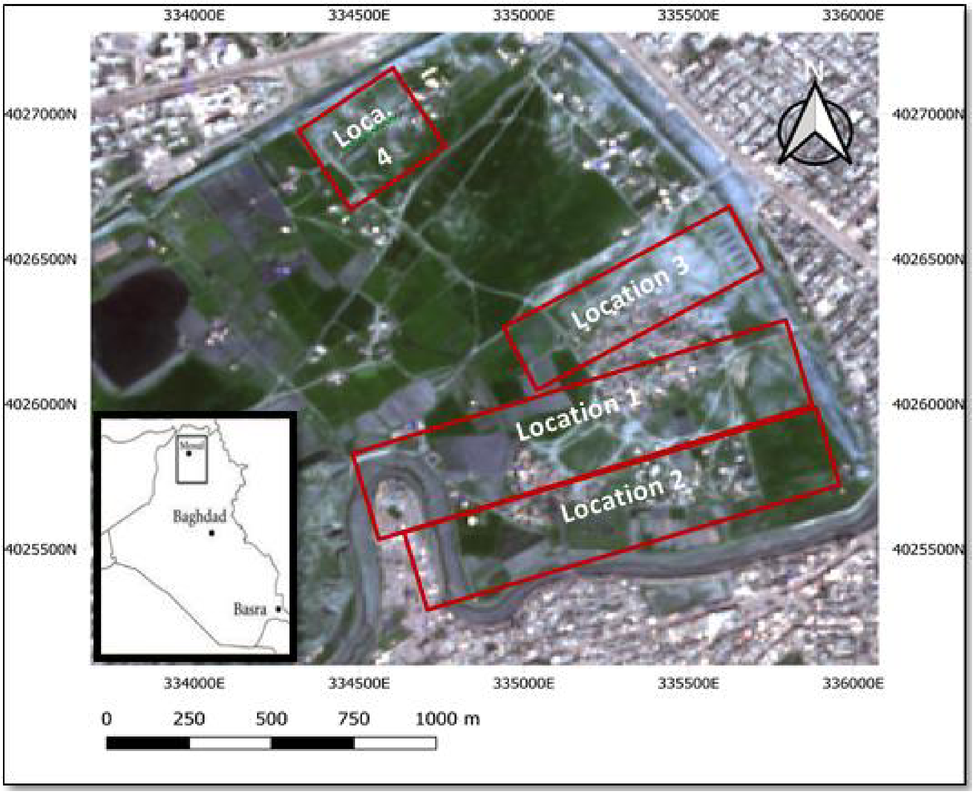


FIGURE 1. The study area, the Nineveh archaeological city, in the center of Mosul, the four survey locations were explained by red color

ing the capital of the ancient Assyrian Empire (Scardozzi, 2011). Where it was established during King Sennacherib's period and made it a defensive line to protect the empire from foreign military attacks. It also included archaeological evidence of weapons in several camps and stores (Ur, 2005).

Many drone flight trips were done in November 2018 after obtaining official approvals and in collaboration with the Nineveh Directorate of Archaeology and Heritage, security forces co-operation and accompaniment were necessary to cover the field experiment. An aerial survey was performed on four separate locations throughout the region where the drone type DJI Phantom 4 Pro was used (Fig. 2), this drone is one of the modern drones that contains the autopilot's capabilities and decides the GPS ground points that will be used in the mosaic picture collection phase (DJI, n.d.).

Despite the historical and archaeological importance of the region, it has been noted in recent years that more and more abuses have taken place, such as the construction of residential areas, ceramic and stone warehouses (Fig. 3).

Utilizing the advanced Pix4Dfields software, drone images were uploaded and analyzed. Where the software

FIGURE 2. DJI Phantom 4 Pro, the drone used in this research

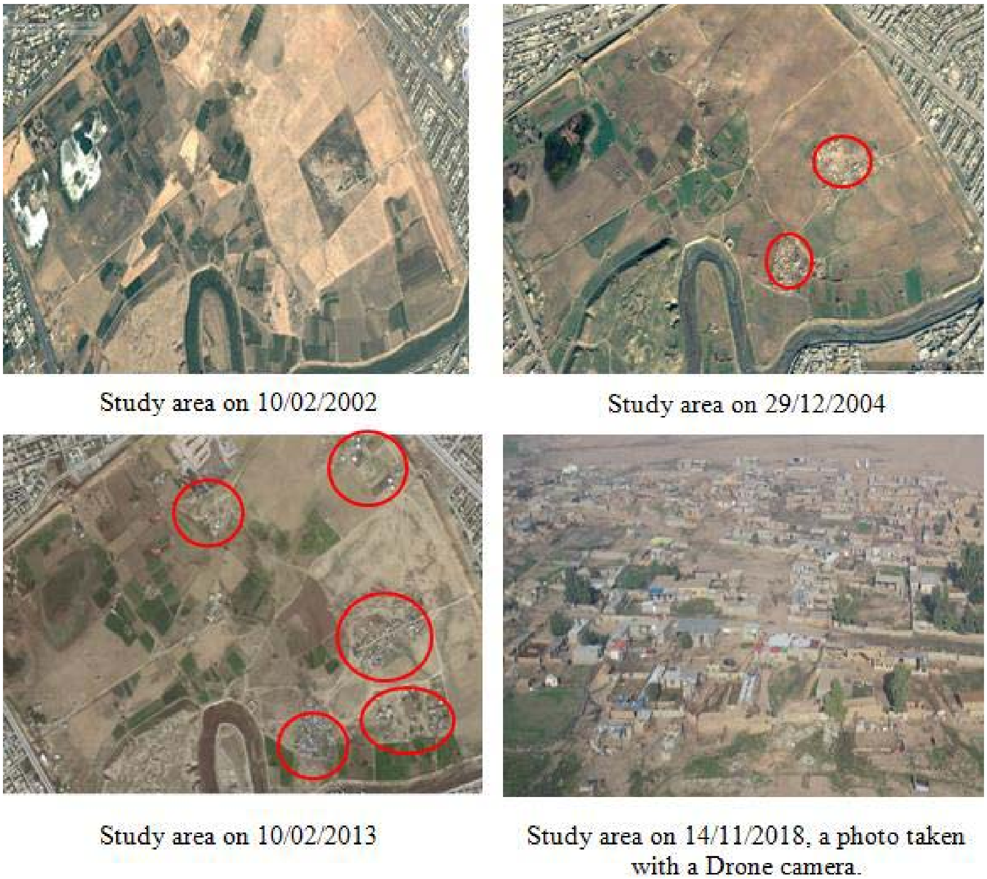


FIGURE 3. An indicator of the violations in the field of research has risen over the years from 2003 to 2018 by using satellite and drone images

includes the possibilities for the use of geographical coordinates and the specific overlapping mosaic function for the region being surveyed. The software also includes the possibility of using mathematical equations to apply engineering indicators to gain more engineering measures from the images (Pix4D, n.d.).

Acquisition and processing pipeline for drone images

Every traditional drone air survey needs some main phases which sum up in this paragraph (Fig. 4) (Colomina, Blázquez, Molina, Paréz & Wis, 2004). The first stage is the planning stage, where this stage reflects the key preparation for the entire process, including deciding the devices available for the survey and choosing the optimal flight time and date.

The second step consists of the images-taken process, which includes the preparation and orientation of the camera, its calibration, its location on the drone. After capturing the images, the stage of gathering these images begins, which is known as mosaic process, where we take advantage of the interference process that we mentioned in the previous stage in order to have a single visualization. All images taken from one location are included in one single visualization. In the final stage, the approach of extracting the information we need from the completed scene and the application of digital processing and photogrammetry processes to find measurements in engineering. For instance, areas and boundaries, characteristics extraction, 3D modeling, or digital and surface model extraction (Nex & Remondino, 2014).

At the mission planning stage, the flight parameter was adjusted and set at 100 m altitude for the control of a drone to achieve a resolution of approximately less than 10 cm per pixel. The pictures were taken in a serial manner and are

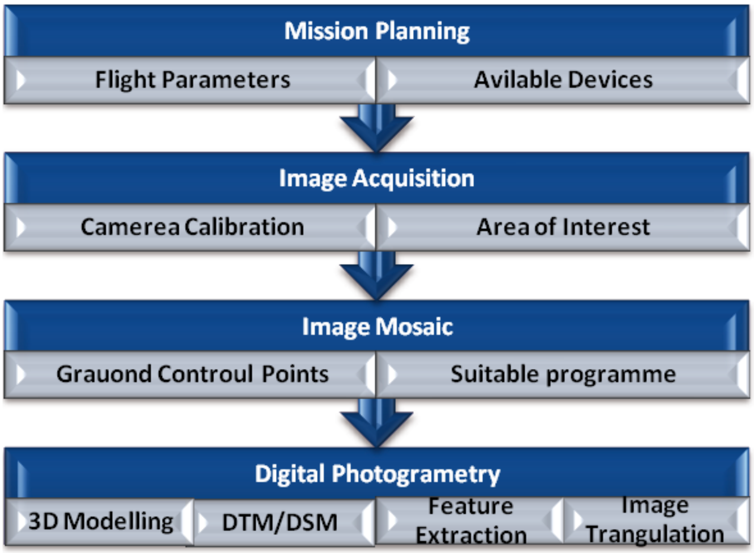


FIGURE 4. Typical acquisition and processing pipeline for drone images

stored in the memory accompanying the drone according to their digital sequence and with an interruption allowing the mosaic phase to be performed. In the information storage area for every image, the geographical location information and geographical coordinates are also stored. Figure 5 gives an example of the serial photos taken with a drone portable camera at the first location. After the scanning process was complete, the captured images will be moved to the computer for the preparation and processing of the entire location show.

Figure 6 shows the use of the proficient Pix4Dfields software to access

FIGURE 5. Sample of a serial picture captured using a drone

FIGURE 6. Processing of the collection images using a mosaic mechanism, projected onto its true geographical coordinates, the direction of route and number of flight lines is clarifies

the sample photos taken for the photography's first location, where the system performs the spatial return process according to the information stored in the pictures. The figure also demonstrates the direction of the route and number of lines covered by the survey (which were here eight lines). That covered nearly 30,000 m^2 in the field. The program also shows, to the left of Figure 6, the length of time taken by the survey, i.e. 22 min, in addition to the start time and date of the survey, which is 8.49 am on 14 November 2018. The four locations view captured by the scanning process are shown in Figure 7 following the completion of the mosaic and projection phase.

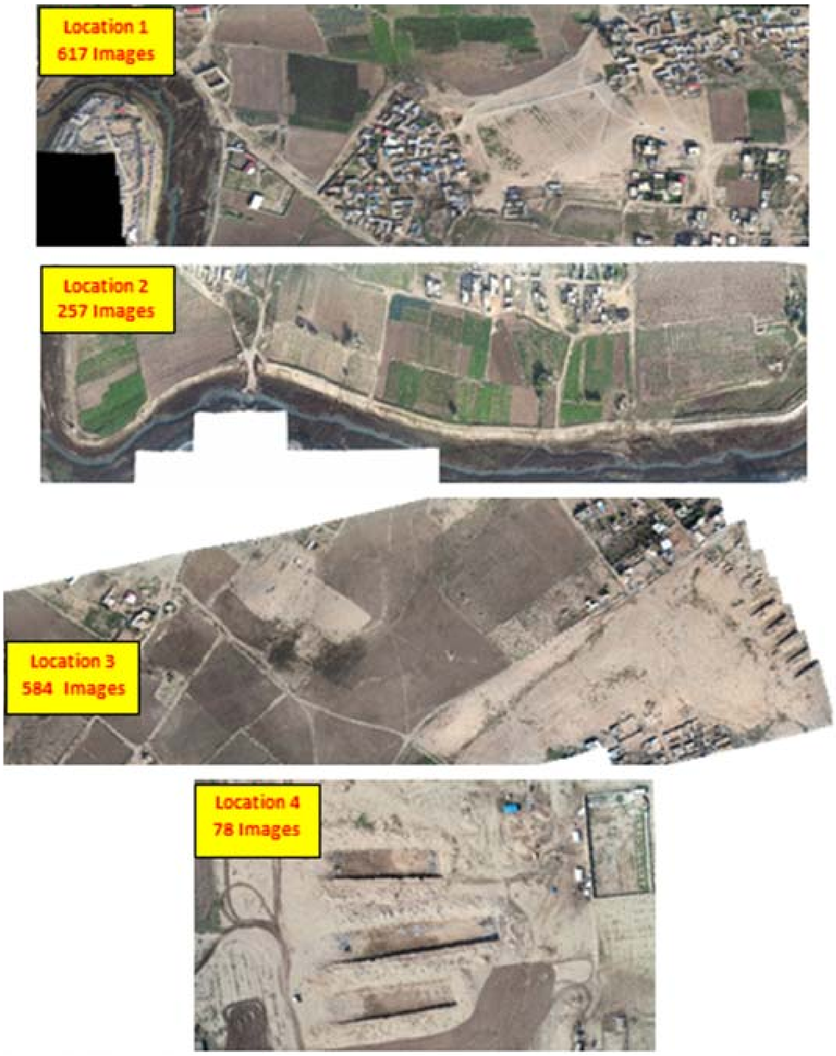


FIGURE 7. Shows the four aerial survey locations after the mosaic's operation

Results and discussion

The stage of analysis and information generation

After completing the process of all locations, the Pix4D program was used to extract information from the surveying process and make comparisons, analyzing, and studying. In this paragraph, we provide examples of information that can be extracted from the drone's survey. Figure 8 shows the example of the amount of archaeological area overtaking in the river Al-Khosr curvature in the first location, where this location has become a group of large warehouses for ceramics that have overlooked, cut, and even sold for a high amount of money in the absence of oversight and confusion during the invasion of ISIS period. The high spatial resolution of drone images enables you to understand the boundaries and measure the areas, moreover small their size may be, decide their type, whether ceramic stores, residences or animal shelters are high-precision, and to punish those who crossed by their limits and range.

Figure 9 shows the excavations that took place between 2013 and 2018 at

FIGURE 8. Shows the amount of overtaking of the archaeological area in the curvature of the river Al-Khosr, where it has become large ceramic stores

FIGURE 9. The difference in the third survey location between 2013 and 2018 and an indication of the overtaking and drilling process that took in the site

the third location as a different example, which gives locations of archaeological excavations carried out by thieves to search for any relics or statues buried under the archaeological hill from the eastern side of the region. The figure also shows the use of large mechanisms for drilling and excavations, which is inconsistent with the mechanisms and laws of archaeologists.

Figure 10 shows the same method of drilling mechanism at the fourth site of the survey, which suggests that the excavators do not have any scientific background in archaeology, and their aim is only to extract what can be extracted and benefit from it financially.

The Pix4Dfields software offers an extensive opportunity to apply mathematical equations to identify several agricultural indicators to track crop typology at archaeological sites and allow the cultivation of species only permitted under legal contracts with farmers under the Department of Antiquities, which are not extended to a specific land depth of land and that may have an impact on the relics. Figure 11 shows an example of the

FIGURE 10. Explanation of the difference at the fourth survey location between 2013 and 2018 and the drilling and overtaking process occurring at the location

FIGURE 11. Implementation of the VARI at the third location of the survey

application of one of the agricultural indicators at the third survey location. This indicator called the visible atmospheric resistant index (VARI) (Eng, Ismail, Hashim & Baharum, 2019), as shown in Eq. (1):

$$VARI = \min\{\max[-(GREEN - RED) / / (GREEN + RED - BLUE)]\} \quad (1)$$

which relies on the visible spectrum of the RGB to use's as one of the indications for the existence of agricultural land.

Archaeological land classification using k-mean clustering

In this research, the archaeological lands were classified using an unsupervised k-mean clustering algorithm for one of the survey sites, as an example, the fourth site was chosen, during different periods of time to find out the extent of overtaking them and their impact on civil works that lead to the loss of their historical importance and heritage value. The proposed archaeological land classification framework showed in Figure 12. After reading the images in step one, the average color of the whole image was obtained, the normalized RGB values were calculated as normalization, which had been used to reduce the effect of illumination. The following normalization scheme was applied to the color index as in Eqs. (2), (3) and (4) (Saberioon et al., 2014):

$$R = R / (R + G + B) \quad (2)$$

$$G = G / (R + G + B) \quad (3)$$

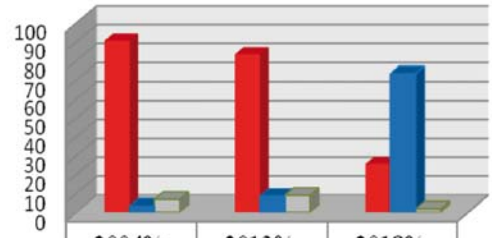
$$B = B / (R + G + B) \quad (4)$$

where R, G, and B are the digital numbers of the red, green, and blue bands, respectively.

In the third step, the VARI index was calculated, as an indicator that indicates the degree of the land change or any excavations that occurred, whether agricultural tillage or archaeological excavation. In the final step, the k-mean clustering algorithm was used, which is considered as one of the most used clustering algorithms due to its efficiency and simplicity. k-Mean clustering classified the land into three classes: archaeological lands; excavation lands; residential building and rocks lands.

The results of the classification in Figure 13 showed the great abuses of archaeological lands in the region, as it appeared that the percentage of archaeological lands in 2004 represented more than 90%, while the excavations and tilled lands did not exceed 3%. While in 2018, the percentage was completely different, as the percentage of archaeological lands appeared to be much less, approximately 25%, next to the large increase in excavations and tilled lands, which amounted to approximately 73%. The category of residential buildings and rocky lands varied from approximately 6.5 in 2004 and increased to 8.7 in 2013, then returned and decreased to approximately 1.6 in 2018 as a result of the Antiquities Department and

FIGURE 12. Proposed archaeological land classification framework



	2004%	2013%	2018%
Archeological Land	90,314	83,125	25,294
Excavation Land	3,087	8,165	73,034
Residential buildings and rocks	6,598	8,708	1,67

FIGURE 13. Classification results using k-mean clustering

Inspectorate beginning to lift some civil and building violations in this area.

Conclusions

Drones technology has rapidly become critical tools for use in archaeological remote sensing and may be limited compared to geophysical methods, but their cost-effectiveness, ease of use, and efficiency make them more widely used and useful for larger and larger surveys. In this study, for the first time in the governorate of Nineveh in Iraq, modern drones technology was used in the phase of surveying the archaeological region of Nineveh, firstly because of its historical importance and secondly because of the great losses that changed its characteristics during the invasion of ISIS. The software specializing in the image processing of this technique called Pix4D has also been used in this research. The UAVs data classification was adopted using a k-means clustering algorithm. The results of the data classification for three different time periods indicated that the percentage of archaeological lands decreased from 90.31% in 2004 to 25.29% in 2018. The research showed the importance and the great benefits of using these systems in the field of archaeology. It concluded that drones data collected provide additional benefits for researchers and policymakers interested in documenting damage to archaeological and heritage sites which will be of great help in preserving the important archaeological sites. Researchers also recommend that local authorities and antique directorates are encouraged to obtaining and use of such systems to protect our archaeological sites from overtaking, vandalism, and theft, as well as their cost, time, and effort savings.

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Summary

Detecting abuses in archaeological areas using k-mean clustering analysis and UAVs/drones data. Unmanned aerial vehicles (UAVs) or drones have made great progress in aerial surveys to research and discover heritage sites and archaeological areas, particularly after having developed their technical capabilities to carry various sensors onboard, whether they are conventional cameras, multispectral cameras, and thermal sensors. The objective of this research is to use the drone technology and

k-mean clustering algorithm for the first time in Nineveh Governorate in Iraq to reveal the extent of civil excesses and random construction, as well as the looting and theft that occur in the archaeological areas. DJI Phantom 4 Pro drone was used, in addition to using the specialized Pix4D program to process drone images and make mosaics for them. Multiple flights were performed using a drone to survey multiple locations throughout the area and compare them with satellite images during different years. Drone's data classification was implemented using a k-means clustering algorithm. The results of the data classification for three different time periods indicated that the percentage of archaeological lands decreased from 90.31% in 2004 to 25.29% in 2018. Where the work revealed the extent of the archaeological area's great violations. The study also emphasized the importance of directing authorities of local antiquities to ensure the use of drone's technology to obtain statistical and methodological reports periodically to assess archaeological damage and to avoid overtaking, stolen and looted of these sites.

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