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Engineering and Architecture Applications based on Unmanned Aerial Vehicles, UAV

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Abstract

Purpose:
The objective of this paper is to show several applications made in the Engineering and Architecture context using Unmanned Aerial Vehicle UAVs by the Researching Group AGR-199 in the University of Almería (Spain).

Method:
Several kinds of UAVs have been applied to different projects, including the surveying campaign to control the accuracy of the results, planning of the flight paths and actions on the flight and post-processing of the acquired data, images or videos. In that last phase, one of the most applied techniques was the UAV-photogrammetry.

Result:
A wide variety of UAV based projects are included in this section: Assessing some yield components in a sunflower crop; surveying and control of a landslide in a road embankment; architectural heritage conservation; archaeology; and updating cartography and infrastructure control.

Discussion & Conclusion:
Considering all the projects and results described in this paper, the UAV based projects and UAV-photogrammetry in particular have be shown to be a low cost, adaptable and efficient technology for complex surfaces modelling.

1 Introduction

In most of the Engineering and Architecture projects is necessary to have availability of graphical data. The object to be transformed in the project has to be geometrically defined in the previous state to the project execution, including the terrain in which the actuation will be carried out, previous buildings or infrastructures.

Several techniques included in the Graphical Engineering topics, are applied to obtain that geometrical definition, e.g. photography records, classical surveying, close-range photogrammetry, land prospections or excavations.

Recently a new technology based on military developments, has been adapted to civil applications [1]. Unmanned Aerial Vehicles, UAV, are programed to flights in the proximity of the target object, with digital video cameras or photo cameras on board, handy controlled by remote control or programmed to collect graphical data. They provide a new point of view of the target object, and can adapt their distance and orientation to the required accuracy for the information in a certain project.

The objective of this paper is to show several applications made in the Engineering and Architecture context using UAVs by the Researching Group AGR-199 in the University of Almería (Spain).

2 Materials and Methods

The size of the UAV can be related to the distance of the flight that can be done in an autonomous mode. In all the cases exposed in this paper, the UAVs used were small, which means moderate costs, wingspan lower than 2 meter and time autonomy of flight lower than 1 hour.

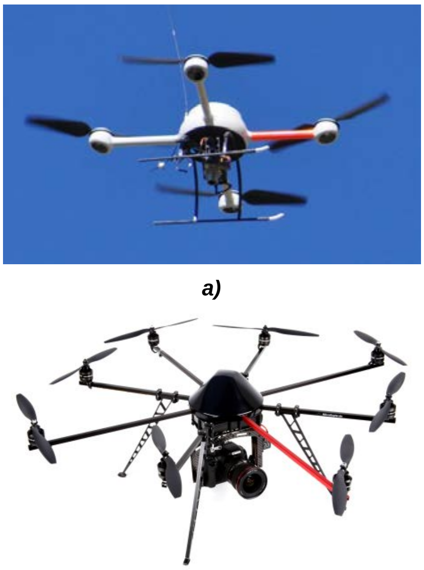
a)

b)

Fig. 1 Fixed wing UAVs. a) Aeromao [1] b) LP960 by Lehmann Aviation [2].

Depending on the system of the flight, the UAVs can be classified in fixed wing (fig. 1) [2], [3] and rotatory helix (fig. 2) [4], [5].

While the first group need more surface for taking off and landing, the second one carries out the manoeuvres vertically. Other characteristics are that fixed wing UAVs usually flight at a higher distance from the target surface, have more autonomy of flight and playload weight capacity than rotatory helix UAVs.



a)

b)

Fig. 2 Rotatory helix UAVs. a) md4-200 by Microdrones GmbH [3] b) UFOCAM XXL8 by Mikrokopter [4].

But the main operative difference is that the rotatory helix UAVs can be in a hold position when they have to take pictures or execute some other programmed action while fixed wing UAVs have to maintain in a constant movement. Therefore, the point of view from rotatory helix UAVs varies from vertical to horizontal and some other intermediate angles, while the obtained data from fixed wing UAVs usually is similar to a conventional flight.

All of them have the possibility of programming the flight planning by specific software (fig. 3) and loading the actions list on the UAV on-board memory.

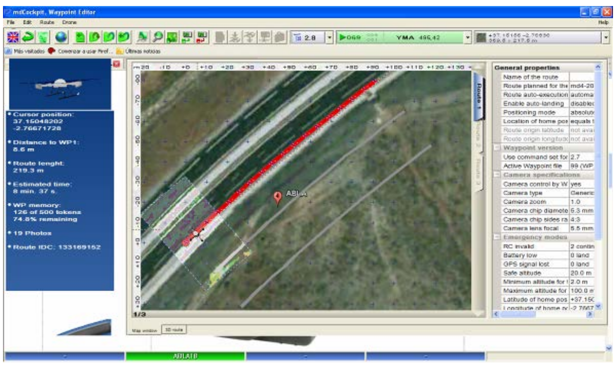


Fig. 3 Md-Cockpit, software for flight planning by Microdrones.

UAVs are equipped with GPS antenna, altimeter and magnetometer to calculate the position coordinates during the flight. Several signals from the navigation tools (accelerometers, gyroscopes, air pressure, humidity and temperature sensors, etc.) are emitted to a base station by radio transmitter and are saved on the on-board flight recorder which permits a post-flight analysis.

Regarding to the cameras, only sensible to the visible spectrum, or sensible to infrared as well as visible spectrum, were chosen depending on the type of target surface. The vegetal surfaces have a characteristic behaviour in the infrared spectrum.

Both compact and reflex cameras were used with capacity to take images and video (fig. 2). The resolution of the cameras varied from 12 to 14.2 megapixels and the focal length interval goes from eyefish to teleobjective. The cameras used to carry out photogrammetric projects have to be geometrically calibrated [6].

Accuracy of the final products, height of flight, type of lens and the UAV playload capacity are the variables which have to be account to choose the model of camera.

In order to take high resolution video, a specific video-camera was mounted on a UAV with a self-leveling platform controlled by servo engines.

The post processing of the acquired data from UAV covers a wide range of techniques. Belonging to the Image Analysis topics, enhancement of images, filtering, lines and features detection, and supervised and unsupervised classification can be mentioned [7], [8].

Applying UAV-photogrammetry, that is, a particular adaptation of the well-known close range photogrammetry [9], typical products can be obtained like digital elevation models (DEM), contours maps and orthoimages.

Video edition is carried out from the videos recorded by the UAVs. Furthermore, specific software is used to make virtual reconstructions and animations based on some of the photogrammetric products.

3 Results and discussion

In this section, some of the main applications carried out by our researching group are summarized, all of them based on images and videos acquired with UAV.

3.1 Assessing some yield components in a sunflower crop

In that project, the capacity of multitemporal and multispectral images (red and near infrared bands), acquired from an unmanned aerial vehicle platform during the growth season of a sunflower crop at different times of the day and with different resolutions to estimate the normalized difference vegetation index (NDVI) was checked [10]. Then, its relationship with several indices related to crop yield was studied, with the aim of generate useful information to apply precision agriculture techniques.

Fig. 4 One of the false colour images acquired with 1 cm^2 pixel resolution with the ADC Lite Tetracam digital camera from a height of 75 m.

In this case, an ADC Lite Tetracam digital camera was mounted on the md4-200 Microdrones to take a set of images of the field experiment during the crop season (fig. 4).

The surface covered by the crop was detected applying the well-known maximum likelihood classification method [7], [8] to the set of images (fig. 5). The NDVI values were calculated with the red and near infrared digital values recorded on the false colour images for all the crop pixels.

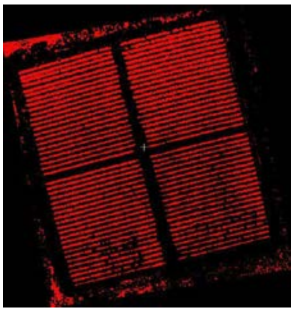


Fig. 5 Image classification output corresponding to the image taken on 27 March. Red represents land classified as sunflower and black the rest of land cover.

The correlation coefficients of the linear regressions fitted between NDVI and grain yield, aerial biomass and nitrogen content in the biomass were statistically significant at the 99% confidence level, except during the very early growth stage, whereas the time of the day when the images were acquired, the classification process, and image resolution had no effect on the results.

3.2 Surveying and control of a landslide in a road embankment

In this work an accurate and low-cost method to characterize landslides located on the size of a road in the province of Almeria (Spain) was developed [11] (fig. 6). The UAV flight was planned to cover the whole extension of the embankment. UAV-Photogrammetric projects were carried out for obtaining DEMs and orthoimages of the landslide (fig. 7, fig. 9).

Fig. 6 Landslide in a road embankment in the kilometric point 339 belonging to the A92 dual carriageway, Spain.

The on-board camera was a low-cost compact 12 Megapixels Pentax Optio A40, sensible in the visible spectrum.

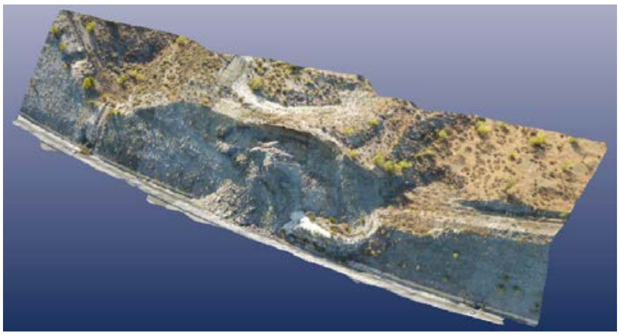


Fig. 7 DEM of the embankment obtained from the vertical photogrammetric project. The landslide can be observe in the centre.

In a first project, 54 images were taken in three paths with the axe in vertical position and it was recorded 85% and 60% longitudinal and transversal overlaps respectively. The orientation of the photos usually is vertical even when the slope of the surface to be recorder is high. But rotatory helix UAV let us to orient the direction of the photos to the target surface, and it can be supposed the total number of photos and overlaps can be reduced. A second project over the same embankment was designed with only 9 images 75% longitudinally overlapped, with the axe in an orthogonal orientation to the average slope of the embankment.

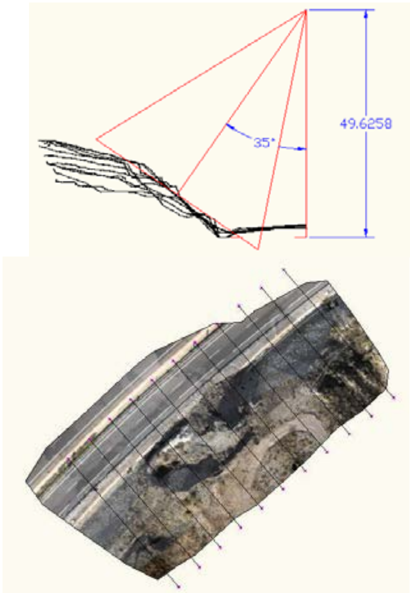


Fig. 8 Calculation of the angle and high of flight by overlapping transversal profiles, or planning the inclined photogrammetric project.

The accuracy of inclined axis photogrammetric projects versus vertical axis ones was evaluated comparing the control point set coordinates, measured on the orthophotos (fig. 9), versus their actual coordinates, measured with a very accurate GPS.

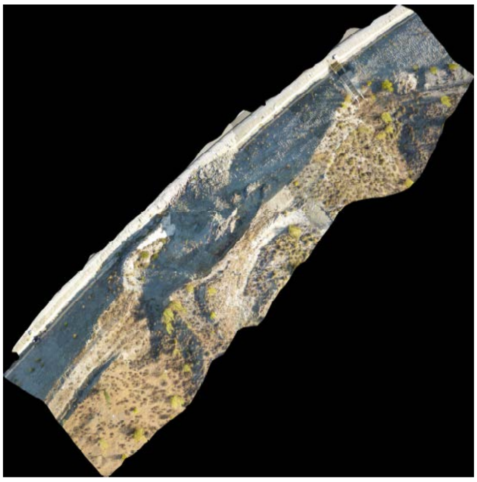


Fig. 9 Orthoimage of the embankment obtained from the vertical photogrametric project.

The planimetric and altimetric errors have showed to be in the same magnitude order in both, vertical and inclined projects, near to 5 and 10 cm respectively. However, the time consuming and complexity of the inclined projects are 30% less than vertical projects in all their phases, flight planning, outdoor campaign and postprocess.

Obviously, the accuracy of the projects lets to take measurements of the landslide and projecting preventive and palliative engineering actuations.

3.3 Architectural heritage conservation

One of the more controverted conservation plans in the province of Almeria affects to a rural building known as “Cortijo del Fraile”. Today, it belongs to private owners and several administrations do not agree about the degree of needed intervention. Meanwhile the damages for the time pass and human actions are more and more evident.

The heritage value of the building is based on the age of the complex (19th century), its typical andalusian agricultural structure and some historical references. One of most famous novel by Federico García Lorca entitled “Bodas de sangre” is based on actual facts happened in the environ of that building.

Fig. 10 “Cortijo del Fraile” sited in Níjar, Almería.

One of the more highlighted buildings in the complex is a small chapel (fig. 10), in which the tower is in serious stability compromised. The roof is not accessible and UAVs provides an especially good point of view for planning the conservation (fig. 11).

Fig. 11 a) Actual image of the Chapel in “Cortijo del Fraile”. b), c) and d) Points of view of the photogrammetic model of the Chapel.

The main economic resource of the province of Almería (Spain) during the century XIX was based on the mining. Today only a few remains exist from the one of the most important factories of lead, located in Adra, called “Fábrica de San Andrés” [12].

The lead foundry was based on a tower, called “Torre de los Perdigones” in which the liquid lead was poured from the top. A water pit in the bottom of the tower cooled the drops, producing lead shots.

The smoke of the process was then brought to another tower far away from the first one, avoiding the very high danger for the workers’ health (fig. 12). The system was very original at that time as beginning of the prevention programs as they are known today.

Fig. 12 a) The main tower in the “San Andrés” lead foundry called “Torre de los Perdigones”. b) The smoke tower in its current state

The local authorities have designed conservation plans to reproduce the architectonics elements belonging to the factory, preserving an important cultural heritage, especially the lead tower, but they have absolutely forgot the smoke tower. Our researching group has developed a study of the second one, and has proposed a new restoration and conservation architectural project based on UAV data [12].

Another study about the Romanic Basilica called “Santa María la Mayor”, sited in Cantabria (Spain) [13] was carried out. The current building is a mixture of parts made in different epochs, although the most remarkable are from later 12th (Apse and Gateway) and 17th centuries (Fig. 13).

Fig. 13 Romanic Apse and Gateway in the romanic basilic "Santa María la Mayor" Cantabria, Spain.

This fact makes this Basilica is a unique piece in Spain and even Europe [14]. The fig. 14 shows four of the phases in the photogrammetric project, to obtain de three-dimensional model.

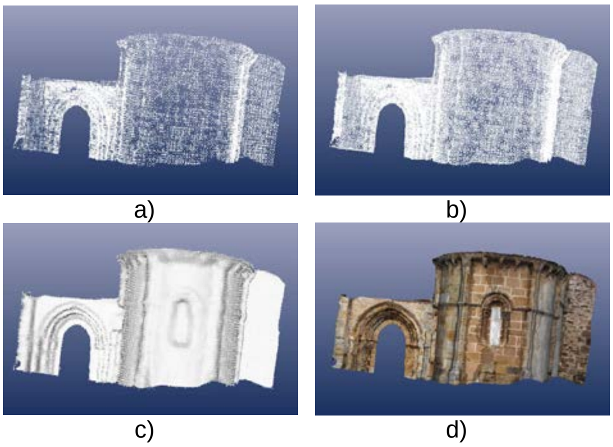


Fig. 14 Four phases of the photogrammetric project. a) Cloud of points obtained by autocorrelation. b) Triangular Irregular Network (TIN) based on the point clouds. c) Surface model interpolated from the TIN. d) Textured surfaces of the three-dimensional model.

In the Heritage of Agricultural Buildings context, another study was developed in order to document and recover the relationship between some elements of a complex flour mill dated on 19th century, known as "Los Terrones", in the "Cortijo Las Cuerdas", Almería province (Spain) [15].

The complex consists of a river diversion dam, an artificial off-stream reservoir, a telescopic irrigation ditch, parallel derivations for the irrigation a terraced plot system, the flour mill, dwellings and some another auxilliar elements.

All the water paths and movement design was made in a very ingenious way because the only energy source was the gravity.

The study included a revision of the heritage and cultural aspects of the different elements, paying special attention to the geometry of the wall that supports the last stretch of the ditch before the flour mill.

It is made of stones and it was modeled by a couple of photogrammetric projects for both faces, integrating UAV and surveying information (fig. 15).

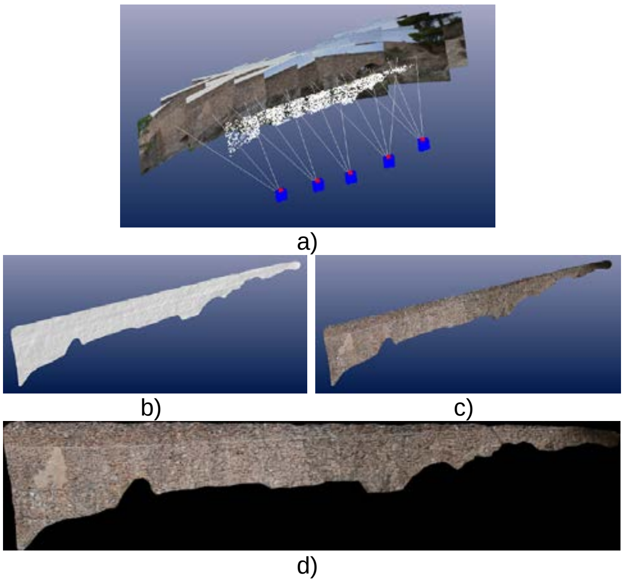


Fig. 15 a) Set of taken images in the eastern face of the wall for the photogrammetric project. b) 3D surfaces. c) Textured surfaces. d) Orthoimages of the eastern face of the world.

Thanks to the products of the study, a stability trouble was encountred in the structure of the wall because the soil erosion under the water path (fig. 16). An actuation to sure its stability is necesary and it can be well planned by the three-dimensional model obtained.

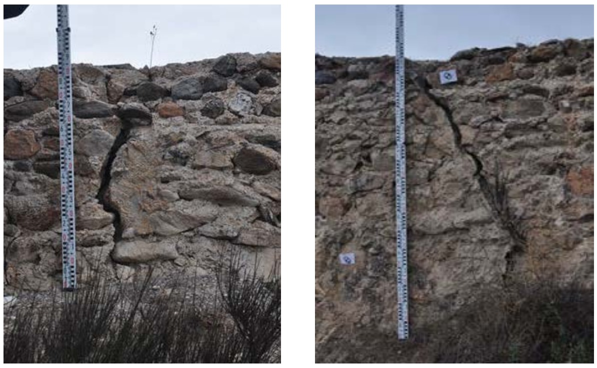


Fig. 16 Detected splits crossin both faces of the wall.

3.4 Archaeology

A singular archaeological site dated on Late Bronze and End of Southeast, called "Cortijo Nuevo", located in the Almería province, was studied from several points of view including the recopilation of previous scientific data and the antecedent administrative documents; generation of a new protection expedient; and carrying out a multidisciplinary and systematic historical study [16].

Our researching group developed a very accurate cartography based on UAV technology, which was the base of all the georeferenced data of the site.

The site was almost unaltered at the beginning of the 1970s. A group of structured made of stones were dug, in a regular disposition and interconnected one each other (fig. 17).

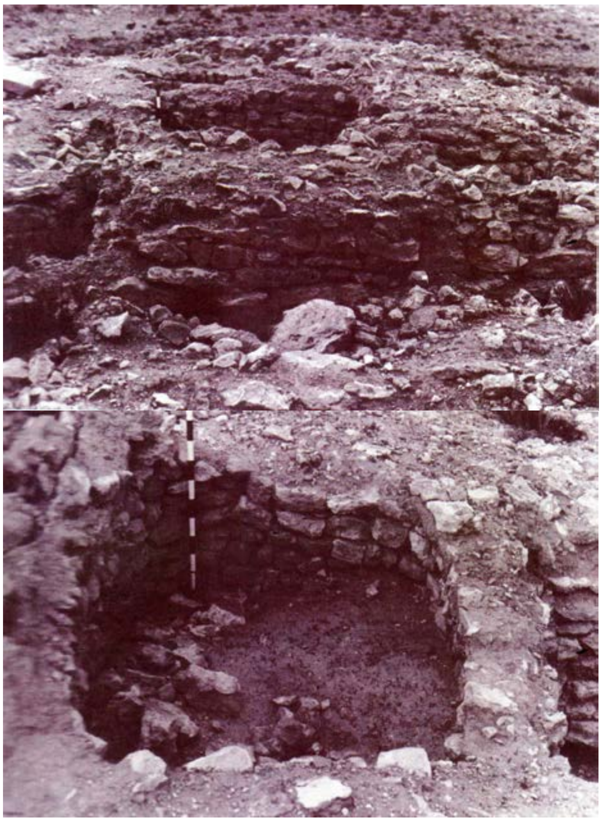


Fig. 16 Structures made of stones dug in the site.

The structures were in a reticular disposal (fig. 17), well adapted to the topography over a soft sloped terrain, with evidences of paving, ashes and vegetal rests and polygonal funerary structures.

Fig. 17 Reticular disposition of the structures.

At the end of the dig campaign carried out in the 1977, no action of protection was made. Some unauthorized works in the area executed in 1970s and 1990s destroyed the most part of the rests, causing a second dig archaeological campaign in 1997.

Today, because of the anthropic actions, no of these structures remain in the site except some dispersed groups of stones. However there are enough evidences to maintain that the site is a very singular because there are no other similar known structures in the Iberian Peninsula.

The study [16] concludes that the structures can be a complex for grain processing in which the hot circulation and the product movement explain the reticular disposal.

Because of the impossibility to reconstruction of the site, the virtual reconstruction is especially useful in order to preserve the heritage and knowledge of the site.

A total amount of 2.2 ha was captured by a rotatory helix UAV. The flight was composed by 6 paths distanced 20 m with 11 images each one, separated every 12 m. It implies a 75% overlap transversal and longitudinal. The high of flight was 80 m over the higher elevation in the site.

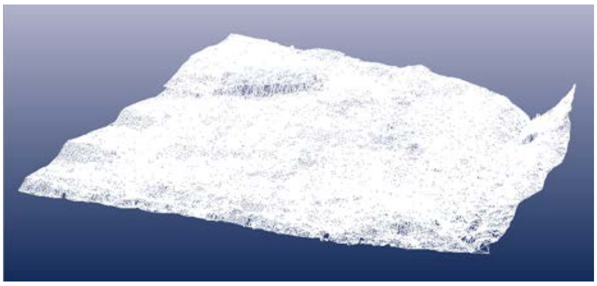
Fig. 18 shows a graphical comparison between the planned and actual paths.

Fig. 18 Two of the planned and actual paths of flight over "Cortijo Nuevo" archaeological site.

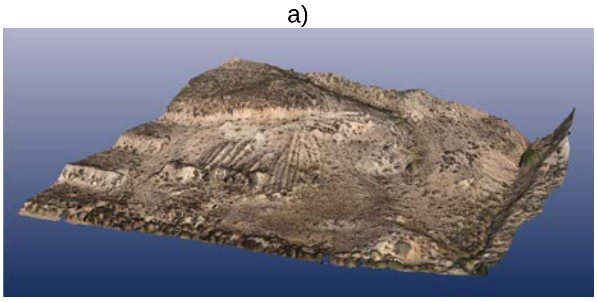
In order to achieve the orientation of the photogrammetric model and control de accuracy of the products, a set of well distributed control and check points were measured (fig. 19), with a GPS in RTK mode with correction post-processing.

Fig. 19 Ground control points (red) and check points (black) for the photogrammetric block orientation and acuracy control, respectively.

In the photogrammetric project, more than 100.000 points were located over the terrain by the autocorrelation algorithm, and a TIN was generated from them with almost 200.000 triangles. Then a soft surface was obtained, applying the texture with a mosaic of images in which the anthropic actions are evident (fig. 20).



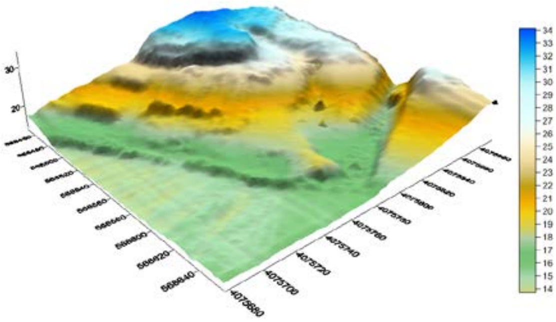
a)



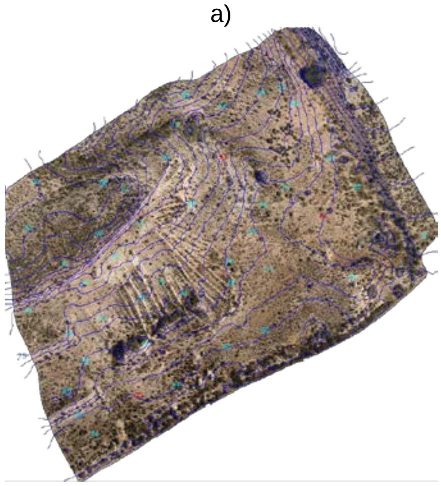
b)

Fig. 20 TIN and textured orthoimages of the "Cortijo Nuevo" archaeological site.

The obtained products from the photogrammetric projects were a DEM interpolated by the Radial Basis Functions method [17], [18] from the 100.000 terrain points, a contour map each 1m and an orthoimage with a 2 cm pixel size (fig. 21). The error committed in the products fell below 5 cm and 10 cm in planimetry and altimetry respectively.



a)



b)

Fig. 21 a) DEM b) Contour lines overlapped to the 2 cm orthoimage of "Cortijo Nuevo" archaeological site.

The knowledge about this archaeological site, and the very accurate graphic information obtained from the UAV project is being integrated in an animation. The objective is to characterize and show not only the current situation of the site, but the achieved conclusions in the digs and archaeological study regarding to the original situation of the elements of the complex, materials, utility and functioning.

3.5 Updating cartography and infrastructure control

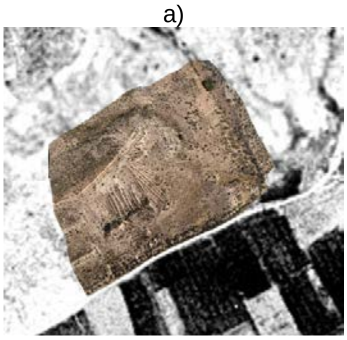
The administrations have basic cartographic information available for the technical users, engineers or architects with aims related to planning and ordering the territory, and some other persons that simply need to locate their works on the territory. But this information has to be updated to represent accurately the reality.

The regional administration in Andalusia has generated at least 9 orthomosaics covering the whole region since the 70s decade, in addition to the northamerican photogrammetric flight made in 1956-1957.

The orthomosaics have the next disadvantages: they are statics and expensive; high cost flights and long post process are needed in their generation; the modifications of the land cover are not updated as frequently as would be desirable; and because of their large extension, its resolution usually is not very high.

Our researching group has a new investigation line regarding to the very high resolution updating, based on UAV technology to updating the general cover orthomosaic. The low cost of the methodology and the possibility of programming the moment to obtain the information would let to include the cost in the budget of the projects that implies land cover change.

a)



b)

Fig 22 a) "Cortijo Nuevo" archeological site image from the oficial orthomosaic corresponding to the 1956-1957 northamerican flight b) The same scene updated with the orthoimage obtained in 2012 by UAV-photogrammetry.

In order to save economical resources, the administrations can detect the land cover changes in a certain moment by image analysis algorithms applied to very high resolution satellite images.

Then the selected land changes are modelled by a UAV-photogrammetry project, updating the official graphical information by overlapping of the new orthoimage to the precedent orthomosaic. For example, fig. 22 shows the official orthomosaic dated in 1956-1957, corresponding to the “Cortijo Nuevo” archaeological site, updated with a 2 cm pixel size orthoimage obtained from a UAV-photogrammetric project in 2012. The anthropic action evidences have been incorporated to the official cartography at a very high resolution.

Another project to control infrastructures was carried out in the San José Port, in the province of Almería. The stability problems in the rock behind the buildings located in the proximity of the main jetty were characterized, where the accessibility was especially difficult (fig 23).

Fig. 23 San José Port. Two points of view taken from a fix helix UAV for stability talus control.

4 Conclusions

The variety of technical problems in which the UAV-photogrammetry has been applied indicates its versatility and potentiality. The main limitations can be the climatic conditions, specially the wind speed and the autonomy of flight. Both are getting better more and more thanks to the new improvements incorporated to the last versions of the UAV programs.

The cost of the whole process (surveying, programing, flight and post-process) is competitive compared to photogrammetric flights with other platforms and classic surveying.

Considering all the projects and results described in the antecedent sections, the UAV-photogrammetry has be shown to be a low cost, adaptable and efficient technology for complex surfaces modelling.

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