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Application of Unmanned Aerial Vehicles in Engineering Practice

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Abstract

Unmanned Aerial System (UAS), also known as 'drone', is an aircraft without a human pilot aboard which has found many applications in various sectors of human activity. Drones were shown useful since they can be used for remote investigations in a very simple manner. They can be navigated by the operator from the ground or conduct an investigation by themselves in a programmed flight path. Recently drones have been effectively used for all purposes in practical engineering,

giving them an advantage over some traditional methods for data acquisition. The most usual type of data that is collected by the drone are high resolution digital images of a specific object or area. With certain overlapping of these images it is possible in post processing to recreate 3D models of specific areas and objects in the form of point cloud, Digital Terrain Model (DTM), or Digital Surface Model (DSM). By using such data and models, it is possible to generate volumes, areas, cross sections and contour lines in a very short time, which are in most cases the basic information in practical engineering.

1. Introduction

Use of UAS in practical engineering delivers a highly privileged aerial point of view. Through this kind of assessment and observation, provided data can be viewed in real time or used later for detailed analysis. The most usual type of data provided by UAS is high resolution photography and video, which makes them ideal for surveying structural objects and areas of interest, especially in hard to approach terrain [1]. Classical technics of surveying (Figure 1) in these types of areas can easily lead to an oversight of critical information. With the development of technologies, software and materials UAS is becoming a tool which can provide owners and engineers with a much bigger perspective for assessing and surveying respecting accuracy and time, which are one of the most important parameters in modern time. Luxury of being able to make fast and correct decisions based on precise and reliable data puts engineers and other interested users in these kind of structures into a really comfortable position. In recent times UAS has been used in a lot of applications regarding surveying, monitoring and mapping of remote objects (indoors or outdoors), although they are hard to reach, hazardous or just more profitable than any other classical method. Various types of final products delivered from UAS data like point clouds, digital terrain models (DTM), digital surface models (DSM) and other types of formats can be used with various software types for planning and designing.
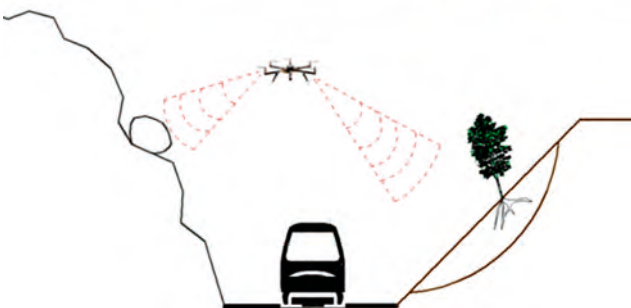

Fig. 1. Replacement of traditional determination of rock block volume by remote sensing via unmanned aerial vehicles

2. UAS

Unmanned Aerial System (UAS) or Unmanned Aerial Vehicle (UAV), commonly and popularly known as "drone" is a flying device or aircraft without the crew and can be operated by remote controller, or fly independently using a prescheduled flight plan [2]. UAS can take different forms, with different levels of controls and the capacity to carry a very wide range of sensors (Figure 2).There are many types supporting different uses, but they are also subject to different regulations. They are built with intelligent stabilization systems to keep them flying and carry sensors to perform dedicated functions. One of the most common devices is a camera mounted on gimbals to obtain high-quality video and still photography [3]. They can be divided into two major groups by constructions which are "rotary wing", Figure 3a and "fixed wing" shown in Figure 3b.

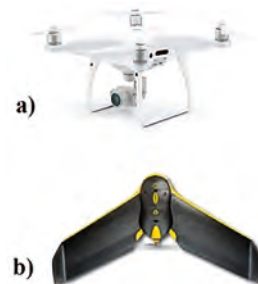**Fig. 2.** Various sensors that can be mounted on UAS

Fig. 3. a) Rotary wing UAS & b) Fixed wing UAS

Each of these types is capable of performing missions for practical engineering, but still each one has advantages and disadvantages shown in Table 1.

Table 1. Comparison of fixed and rotary wing UAS

	Fix wing	Rotary wing
Projects	Larger are mapping	Smaller area mapping, inspection
Applications	Land surveying, agriculture, GIS, environmental, construction	Urban surveying, real estate, construction surveying and mapping
Cruising speed	High	Low
Coverage	Large	Small
Object resolution	Cm/inch per pixel	Mm per pixel
Take-off/landing area	Large	Very small
Flight time & wind resistance	High	Low

One of the most typical types of UAS used for practical engineering is rotary wing DJI Phantom 4 Pro [4]. It is a quadcopter drone that can be also called "ready to fly", meaning all of its components are already built in. In order to use this type of UAS for data collection its most important specifications are camera resolution, flight time, shutter type, built in GPS antenna (Global Positioning System), camera stabilization system and ability to perform autonomous flight operation. It is operated by the remote controller who has attached a tablet computer on it, which is used to set up all the drone's functions and also has live preview from the camera (Figure 4).

Fig. 4. UAS DJI Phantom 4 Pro with corresponding remote controller and tablet computer

One of its very useful functions is to remotely transfer real time preview (live stream) to another place through a mobile data connection. This kind of interactive approach can offer the evaluation of on-site condition to the persons who are at other locations (offices, cabinets, laboratories). They can focus more on receiving live fed and navigate the on-site operator to take more detailed pictures or videos of the specific area of interest [2]. A schematic view of how it works can be seen in Figure 5.
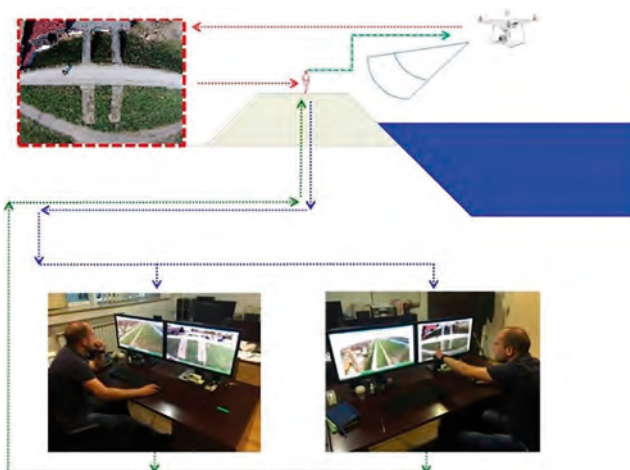

Fig. 5. Interactive scheme for engineering prospection

3. Creating 3D model

In order to create a three-dimensional model of a terrain or structure, a considerable number of photographs of the area must be taken with longitudinal and transverse overlapping between the photographs. The principal objective of the computer program is to link these photographs into a single whole, and to generate a point cloud using the following steps [5, 6, 7]:

1. identify similarities between the digital photos,
2. derive the SfM (Structure from Motion) algorithm,
3. make geo-references,
4. finalise the process and make image changes as needed.

The final result of the above procedure is the point cloud (Figure 6) that consists of a set of points in a given coordinate system. In the three-dimensional coordinate system, these points are defined by X, Y and Z coordinates, and they most represent the external surface of an object. In addition to coordinates, the point cloud also contains the data about the lighting, time of survey, and colour of every point within the cloud.

One of the softwares that uses this kind of procedure for creating 3D models is Pix4Dmapper [8]. It processes the images that were taken from the air using unmanned aircraft, or from the ground with digital camera. To do so, it uses SFM (Structure From Motion) algorithm that works on the principle of recognizing the image content (pixels) in order to make a complete 3D model of the subject in the form of creating a point cloud. The software is completely adaptable to all types of cameras and image processing results can be converted and used by any GIS or CAD applications. Pix4D-mapper can be used in many different branches of industry and science, such as mining, agriculture, geodesy, civil engineering, management of natural resources and emergency services, and allows the following:

- line and polyline measurement (break lines), making longitudinal and cross sections, contour drawing, measuring areas and volumes directly in the model and their export to other different formats
- generating 3D point cloud, true orthomosaic and orthophoto maps, 3D textured models, DSM (Digital Surface Model), DTM (Digital Terrain Model) from vertical and oblique aerial or terrestrial photos
- it uses a fully automated flow of data processing and calibration of each photo in order to achieve a satisfactory level of accuracy, but also the "Rapid Check mode" for checking the quality of recording directly on the field
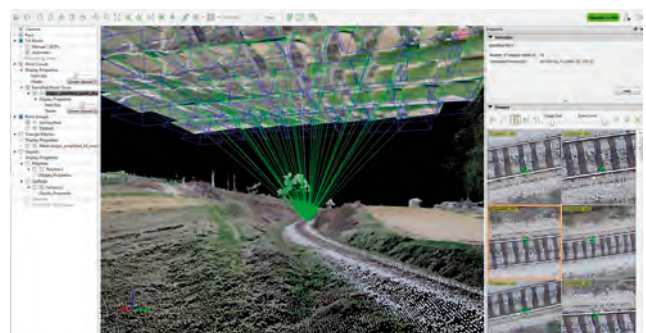

Fig. 6. Interactive scheme for engineering prospection

4. Data acquisition

Upon the arrival at the location the first step is to prepare an autonomous flight mission for UAS by defining the area of interest [9]. Through that procedure it is necessary to set up parameters for flight which include the height of the flight, angle of the camera view, longitudinal and side overlapping of the images and UAS speed. All these parameters are important for determining GSD (Ground Sample Distance) of the future model. GSD is the distance between two consecutive pixel centres measured on the ground. The bigger the value of the image GSD, the lower the spatial resolution of the image and the less visible details. The GSD is related to the flight height: the higher the altitude of the flight, the bigger is GSD value [10]. The whole procedure is done in interactive application installed on the tablet computer, and the one used in this case is "Pix4Dcapture" [11], (Figure 7).

Fig. 7. Application screen for setting up flight mission

Depending on the area of interest, various types of missions can be selected and performed. The most usual mission types are "grid" and "double grid" which are suitable for flat areas and terrains. More complex missions like "circular" and "free flight" are performed when the object, or area of survey is placed in vertical position, urban areas or areas with a lot of obstacles that can endanger the flight. These types of missions directly depend on the experience and competence of the pilot navigating UAS.

5. UAS survey for practical engineering

5.1 Sava embankment

At the location a total of 117 images were taken. All images were geo-located at the time of exposure (Figure
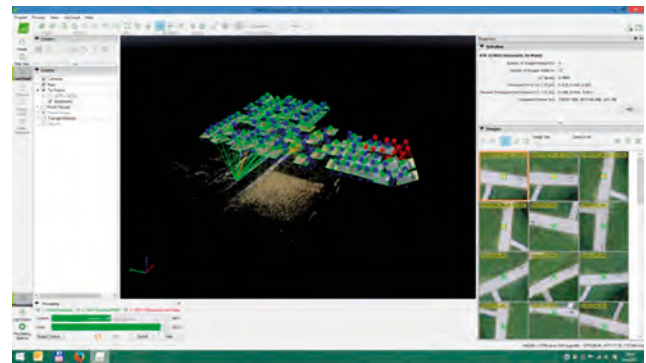

Fig. 8. Visible point cloud and aerial positions of images

8) and the overall area covered by flight was 3.69 hectare, which was enough to make the quality analysis of embankment. Images taken from UAS were imported into "Pix4D mapper" and processed.

One of the first noticeable things after processing the images was so called "Uncalibrated Cameras". The reason why did it happen is the impossibility of the software to find enough matches on neighbouring images to create a stereoscopic effect and by that not able to crate 3D points. These 14 images were created above water, (Figure 9.) and as water was moving it changed its surface making it impossible to create points.
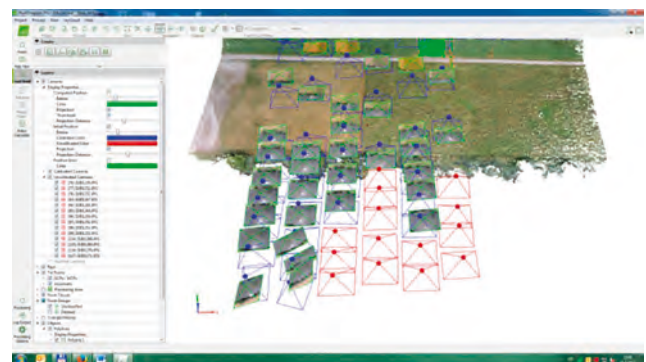

Fig. 9. Uncalibrated Cameras visible in red colour

The overall processing time was 1.5 hours, which combined with flight preparation and flight time, taking 30 minutes, which altogether amounted to around 2 hours. The achieved GSD was 2.26 cm creating a number of 7.304.850 3D points shown in Figure 10.
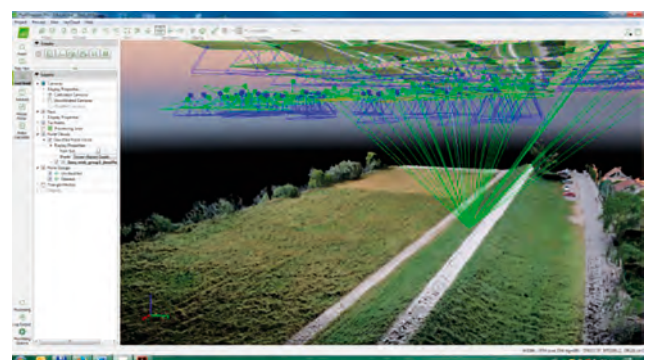

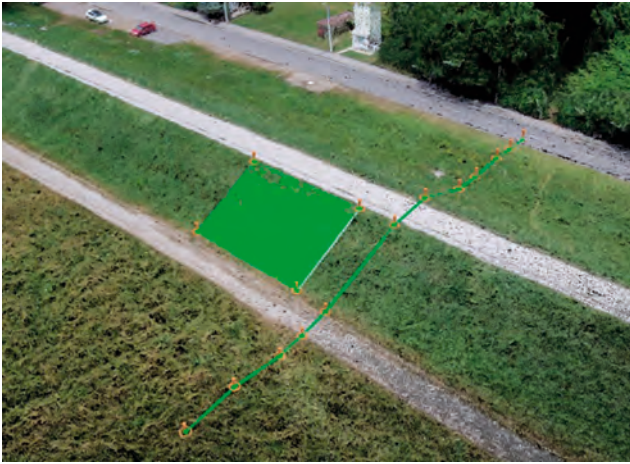**Fig. 10.** Point cloud containing 7.304.850 3D points

Fig. 11. 3D polyline and surface

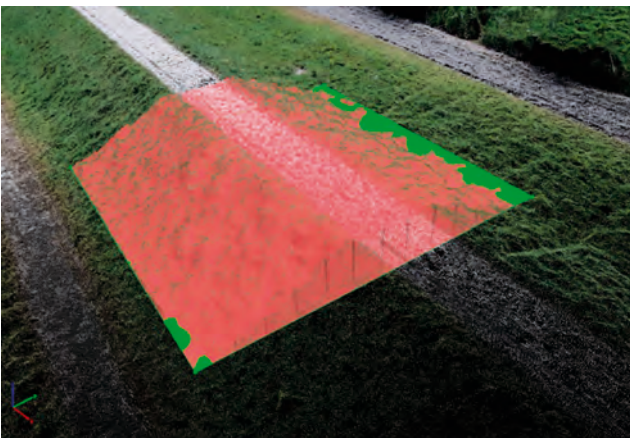**Fig. 14.** Digital Surface Model „DSM"

Fig. 12. Volume calculation

Inside of the software it is possible to create 3D polylines, surfaces, (Figure 11), volume calculations, (Figure 12) and orthoplanes, which all can be exported into other types of formats such are *.dxf, *.shp, *.dgn and *.kml.

Through application called "Mosaic editor" the generation of DSM and DTM is possible. The difference between these two is in filtering out the surface data and leaving only terrain "DTM" (Figure 13), or leaving all the surface data creating "DSM" (Figure 14).
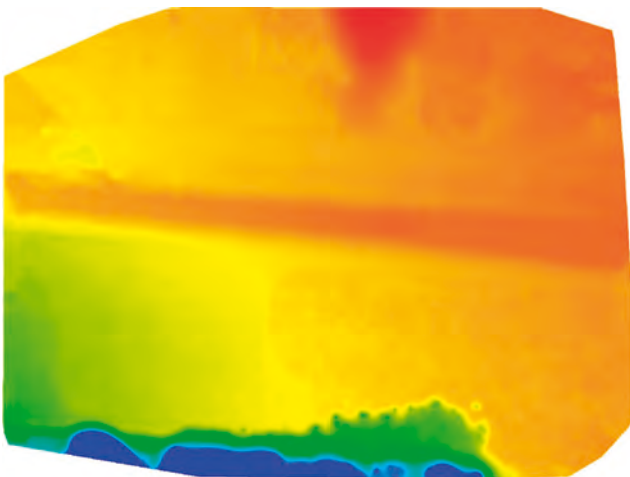
Fig. 13. Digital Terrain Model „DTM"

Fig. 15. Digital Surface Model „DSM"

Also, a digital orthophoto map is created using all taken pictures combining it into one big high resolution map (Figure 15).

5.2 Doljan cutting landslide

Doljan cuttings is situated in km 80+830, railway track R201 Zaprešić – Čakovec between the railway stations Novi Marof – Turčin. The instability in the form of the landslide occurred on the right side of the Cutting (Figure 16).

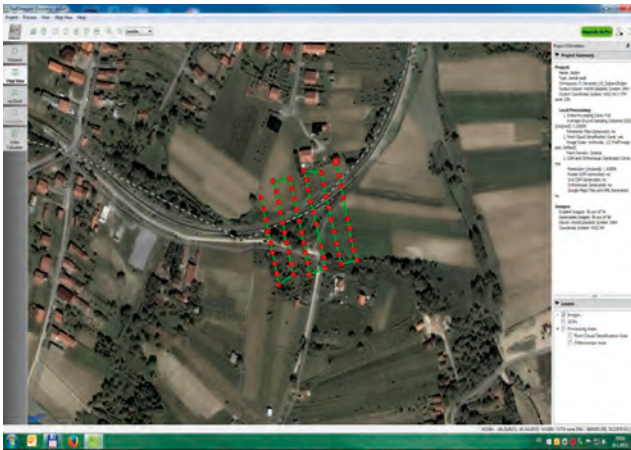**Fig. 16.** Picture of landslide taken from UAS

Fig. 17. Images taken on „Doljan cutting"

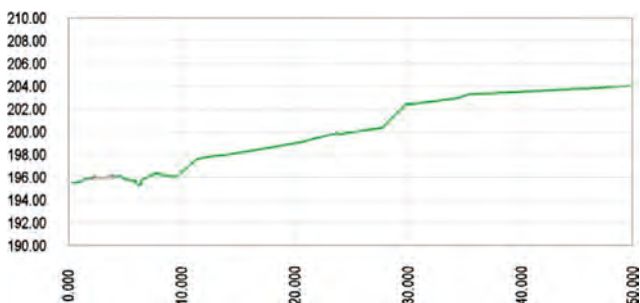**Fig. 18.** Point cloud of „Doljan cutting"

Fig. 19. Cross section extraction

The purpose of the project was to develop a remediation and reparation design in this location that would ensure the permanent stability of the cuttings. Collection of 3D data by conventional surveying methods in these cases can be quite time-consuming, and even dangerous for the field operator. Steep locations like embankments, vertical cuttings and locations
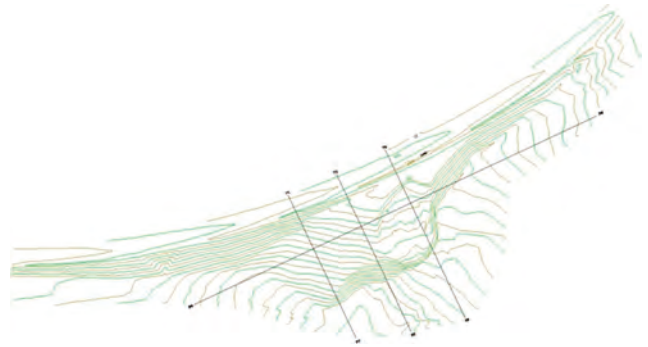

Fig. 20. Generated contour lines from the point cloud

with potential landslides or mudslides, could be given as an example. In such locations, the visual inspection of the terrain as geodetic data collection by classical methods, can result in an incomplete and insufficiently detailed display of the terrain. The use of UAS in these locations can greatly complement, enhance and even completely replace the classical methods of mapping. Upon the arrival at the field it is not required to approach the hazardous location, but come to a safe proximity and send UAS (with a pre-programmed flight or manually guided) to collect the data needed for quality and correct visualization and interpretation. All together 56 images were taken at the field with foot prints and can be seen in Figure 17.

For the purpose of the remediation design, a 3D point cloud was created containing approximately 5 million points (Figure 18).

An extraction from the point cloud was made and given to the designers at specific locations that represent geometry of the landslide in the form of cross sections (Figure 19) and contours (Figure 20).

5.3 Irija – Jelični Vrh, Slovenia rockfall protection

For the purpose of the Ministry of transportation of the Slovenian Republic a survey was carried out to make a calculation of embedded materials in the form of rock fall protection nets and barriers. As the location is situated in a mountainous region right next to regional road number 102, the usage of UAS was a reasonable choice to carry out this task. The slope dimensions were approximately 200 meters in horizontal and 100 meters vertical direction. A free flight mission was performed, and 451 images were taken (Figure 21).
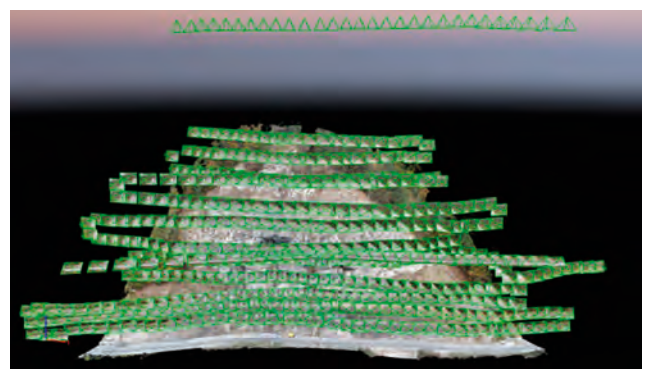

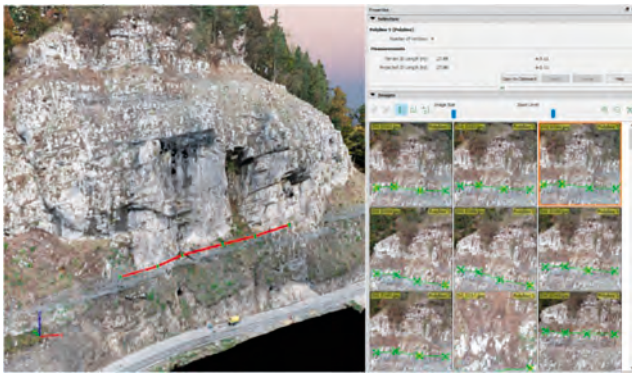**Fig. 21.** Positions of 451 images taken from UAS

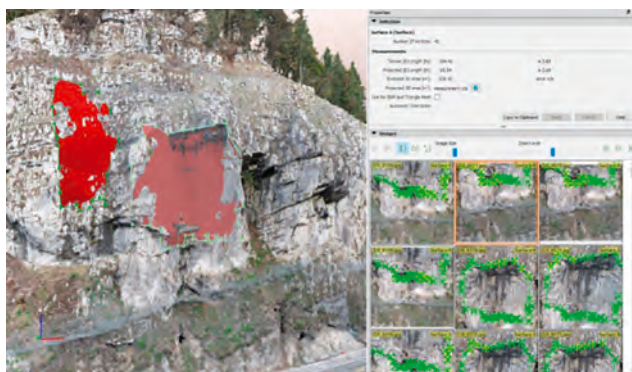**Fig. 22.** Calculation of barrier length from point cloud

Fig. 23. Calculation of 3D areas built in protection nets

The Average Ground Sampling Distance (GSD) was achieved at 1.24 cm per pixel. The calculation of the length built in barriers was done through a point cloud (Figure 22) visible in red colour (on the left) and all images from where this particular barrier is visible, and also the calculation of 3D surfaces in square meters for protection nets (Figure 23).

Conclusion

The use of unmanned aerial systems can greatly broaden, improve, and even fully replace traditional methods for mapping and for determining volumes, cross sections, contour lines and other parameters that are needed for practical engineering analyses. Their use is especially appropriate in case of steep and high cuttings and other hardly accessible sites where the implementation of tra-

ditional survey procedures can sometimes prove hazardous. Despite evident advantages of unmanned aerial system, some limitations do exist with regard to deficiencies of the method itself, and the regulatory framework. One of the major deficiencies is weather. It is impossible to fly in the rain, snow, fog or wind.

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