by M. Yakar

USING CLOSE RANGE PHOTOGRAMMETRY TO MEASURE THE POSITION OF INACCESSIBLE GEOLOGICAL FEATURES

Investigations of major geological formations are very important since they provide vital information in terms of the monitoring of future changes. This article describes the way in which close range photogrammetry can be used to obtain quantitative information on the geometry and strain patterns in an evolving physical model. These models have been widely used to study geological structures for more than 100 years. The greatest benefit of physical models is that with proper scaling of model dimensions and materials, researchers can directly observe structural or tectonic processes that take millions of years to occur naturally.[1]

One of the shortcomings of most geological information such as maps, cross-sections, and outcrop cameras is that they are two-dimensional (2D), while the processes that interest geologists typically occur in three-dimensional (3D) space. The 3D geometry of a geological structure is crucial to quantify the geological processes related to fracture mechanics, such as hydrothermal mineralization and ground water flow, but also geotechnical problems such as rock mass stability. A number of studies have shown that some geological structures can be described with a scale invariant, fractal distribution. So far these observations on which these findings are based were restricted to one and two dimensions and it has been difficult to obtain a full spatial geometric picture of fracture sets from rock outcrops, because much of the rock is not directly accessible. However, without taking into account the spatial distribution of geological structures, the true geometry of joint patterns cannot be fully described and scaling laws, whether fractal or not, cannot be derived.[2] Close range photogrammetry presents images of joint patterns based on datasets acquired by digital photographs, which are processed to 3D images using the photogrammetry software PhotoModeler 5. PhotoModeler is a Windows-based photogrammetry software developed by Eos Systems Incorporated (Vancouver, Canada) and used to accurately model and measure a physical object from digital images. In PhotoModeler, a 3D object model consists primarily of a set of spatial points, edges, and/or curves. Surfaces and textures can later be conveniently added to the basic wire frame model to create a realistic solid model. Measurements of distances such as between two points, lines and points, points and surfaces can be made using the measurement tool. 3D models can be exported in DXF format to AutoCAD, VRML, and other well-known formats. The close range photogrammetric technique can provide a highly accurate 3D model of the visible geological structure.[1,3]

In this study, tectonic Timras doline geological map drawings have been obtained, in Turkey, using digital close range photogrammetric techniques. All rocks and stone layers were determined and documented spatially from the 3D Turkish national coordinate system.

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REGION SETTINGS (TIMRAS DOLINE—TURKEY)

Konya is located on the central Anatolia High plateau of 39,000 km^2, situated between 36°22′ and 39°08′ northern parallels and 31°14′ and 34°05′ Eastern meridians. Cumra, located 47 km southern to the center of Konya, is a gate opening onto the south of Konya Plain. The Toros Mountains start 20 km south of Cumra which has been inhabited since the Heolitic age and today most settlements are located on the plains. The Carsamba River coming from Bozkır and Beysehir towns has an effect on the irrigated farming of Cumra and of Gökhüyük village which is 15 km away. The Timras doline is in this region (Fig. 1).

A doline, also called a sink, or sinkhole, is a topographic depression formed as underlying limestone bedrock dissolved by groundwater. It is considered as the most fundamental structure of karst topography. Karst topography is a landscape shaped by the dissolution of a layer or layers of soluble bedrock, usually carbonate rock such as limestone or dolomite.[4] Sinkholes vary greatly in area and depth and may be very large. There are two main varieties, one caused by the collapse of the roof of a cavern, the other by the gradual dissolving of rock under a soil mantle. Collapsed sinkholes generally have steep rock sides and may receive streams that then flow underground. The soil-mantled sinkhole is generally shallower than the collapsed sinkhole and receives local drainage; it may become clogged with clay and hold a small lake.[5]

As mentioned earlier, there are two different mechanisms for the formation of dolines:

- Solution:
  The corrosive solution of limestone by rainwater is very high in the area of a crack, allowing the water to run into the rock and normally forms the bowl-shaped dolines.
  This process produces large amounts of clay (depending on the pureness of the limestone). This clay is water resistant and sometimes plugs the drainage, so small lakes of rain water can sometimes be found in dolines, a rare thing in waterless karst areas.
- Collapse:
  When a cave grows, there may be a point where the roof of a cavern is not sufficiently stable. This results in several collapses that shape the roof like a dome. This process finishes when the shape is able to hold the weight of overlying rocks.[5]

However, if the overlying layers are too thin and the impact of this collapse reaches the surface, the ceiling collapses and

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Fig. 1: Location of Timras doline on map of Turkey

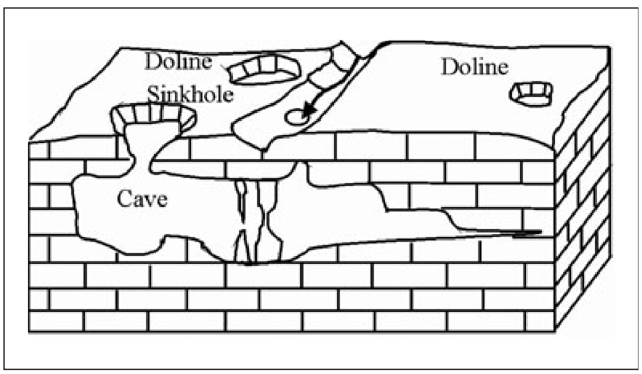


Fig. 2: Doline formation

Fig. 3: Timras doline

a doline is formed. The doline is often a natural entrance to the cave (Fig. 2). The Timras doline in the study area can be seen in Fig. 3. The Timras doline is frustoconical and elliptically shaped. The width of the doline is 250 m and length is 325 m, with a depth of about 35 m.

MATERIAL AND METHOD

Photogrammetry techniques allow the conversion of the images of an object into a 3D model. Using a digital camera with known characteristics (focal length, pixel size, and number of pixels), a minimum of two pictures of an object are required. If the same three object points can be indicated in the two images—if you know the internal parameters of the camera used—with known dimensions, other 3D points in the images can be determined—if you need to compute these parameters you need more ground control points (GCP).[6–11]

The same process can be used to obtain dimensional measurements efficiently on inaccessible structures such as tunnels and dams, and large or complex facilities such as refineries or water-treatment plants. The close range photogrammetric measurements can be integrated with 3D modeling and reverse engineering processes.[7,12]

Research in Austria compared the traditional and photogrammetric methods based on an equal number of workers. The research concluded that the photogrammetric method is more efficient than conventional methods by 100–130 times and 2–5 times graphically and furthermore, it is 10 times more accurate than the traditional methods.[13]

All studies in photogrammetric technique can be completed by only using photographs; this is a noncontact technology. For this reason, the photogrammetric method can be considered particularly for high risk places. It can also be considered useful in the surveying of objects that cannot be physically measured. One of the main features of the photogrammetric method is the short length of time required on-site to carry out the measurements, although office-based work during the evaluation stage is actually longer. Another beneficial factor is that the user does not require specialized knowledge of photogrammetry, and no large-scale investments in equipment are needed.

Photogrammetry techniques allow you to convert images of an object into a 3D model. Using a digital camera with known characteristics (lens focal length, imager size, and number of pixels), you need a minimum of two pictures of an object. If you can indicate the same three object points in the two images and if you can indicate a known dimension, then you can determine other 3D points in the images. The model geometry at any given time is defined by the positions of all the markers, whereas strain and displacement are obtained by comparing or tracking the positions of the markers at different times during an experiment.[1] To demonstrate the versatility and power of the technique, a close range photogrammetric analysis was conducted on two scaled physical models of monoclines that form above basement-involved reverse faults with differing displacement distributions. Comparison of the models allowed the linking of fault displacement and lateral propagation history to unique evolving 3D geometries, showing cover rock displacement and deformation patterns that are unlikely to be revealed by other physical modeling techniques. These links may allow the interpretation in natural settings, of the growth history or displacement patterns of poorly imaged faults that underlie basement uplifts, or facilitate the prediction of the pattern of smaller-scale deformation that might occur within a basement-involved fault-related fold. Close range photogrammetry can be used to generate a spatially referenced 3D image from overlapping digital images such that each pixel of the image is assigned spatial coordinates (x, y, z). As modern digital cameras have resolutions of up to 10 million pixels, this gives spatial resolutions of outcrops in the subcentimeter scale (for camera distances less than 100 m).[6,7]

Field Studies

To be able to make a photogrammetric evaluation of a land use map of the area surrounding a doline, seven numbered traverse points were established. The distributions of the points are shown in Fig. 4.

The values of the traverse coordinates have been measured by an American JavaT GPS double-frequency device with four receivers. The average measurement error is (m_o) = ± 9 mm.[14] Seven points have been measured in static mode with GPS. Coordinate values have been transformed to Turkish national coordinate system by using known points. Some control points marked on rocks and on the edge of the doline and coordinates of these points were also measured using a Topcon GPT-3007 electronic total station instrument (Topcon Corp., Tokyo, Japan). One-hundred and eighteen control points have been measured to make exterior orientation. The Topcon GPT-3007 Series are pulse laser total stations with a superior nonprism measurement capability. Making use of an updated optical system, the GPT-3007 Series incorporates special techniques to provide an accurate, reliable, and safe nonprism distance measurement over a range of up to 250 m. The software provides complete functionality to carry out all surveying, calculations and to store all the data in the instrument. The distance measurement accuracy of instrument is $\pm(2\text{ mm} + 2\text{ ppm})$.[15]

Photographs of the doline were taken after the measurement procedures. An HP 735 digital camera (Hewlett-Packard, Palo Alto, CA) was used to take the photographs according to photogrammetric principles.

Photosmart 735 features:

- 3.2-Megapixel resolution for photo-quality prints and enlargements up to 8 × 10 inches
- 3×optical and 5×digital zoom and macromode for sharp close-ups

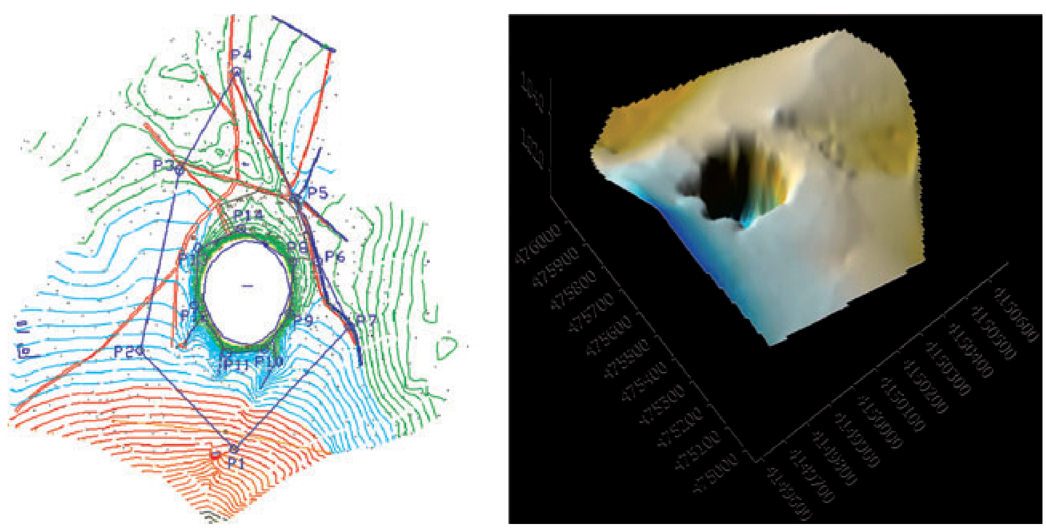


Fig. 4: Topographic map of study area and local network traverse points

- Print photos directly from camera to HP PSC 950 all-in-one or HP Deskjet (excludes 600 series) printer with USB connectivity, no PC required
- Record 320 × 240 video with audio, length limited only by memory
- Record up to 60-s audio memos with still images
- Program AE, aperture priority, and picture modes
- Optical viewfinder and 1.5-inch color LCD screen
- 16 MB internal memory or secure digital memory cards
- Auto exposure, red-eye reduction, and auto flash
- Adjustable ISO, white balance, saturation, and sharpening
- Powered by two AA type batteries
- Docking capability with the optional HP Photosmart 8886 digital camera dock (not included), connect easily to PC or TV and recharge camera batteries

Camera distance to Timras doline is approximately 100–150 m. About 250 photographs have been taken from ground, but only 57 photographs selected and used in project (Fig. 5). All the field studies were completed in 1 day.

Photogrammetric Evaluation

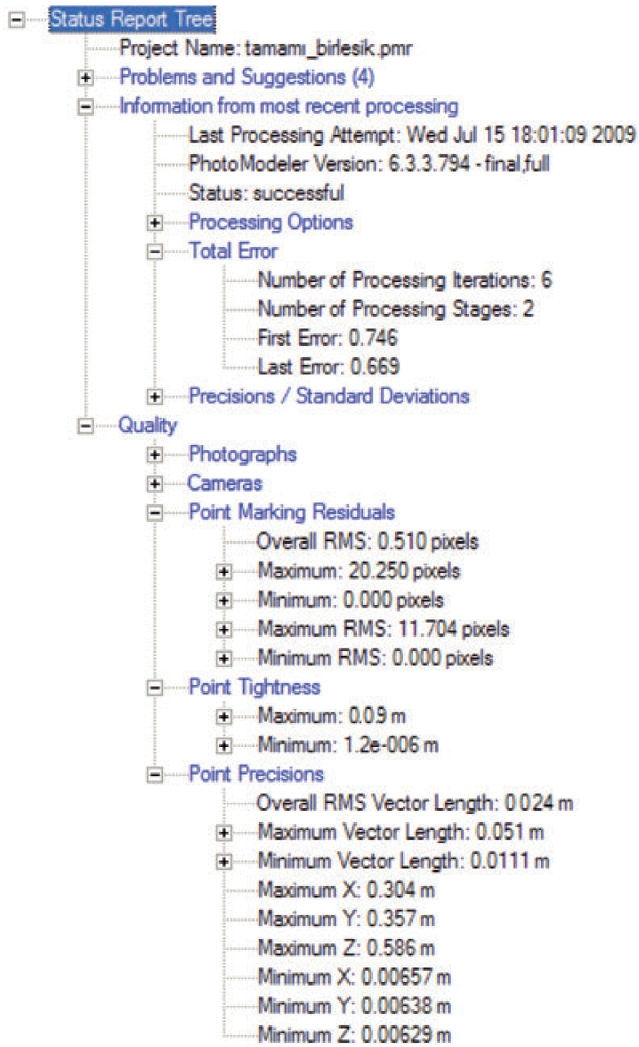
Calibration of the cameras was carried out in the office. This calibration is usually carried out through the analysis of the views of a test object (calibration *target-set*), which usually consists of a set of *fiducial marks* (*targets*), positioned within the 3D volume that is being imaged by the camera system. If the geometrical characteristics of this target-set are only partially known or completely unknown, then the calibration process must include the refinement or the blind estimation of the 3D coordinates of the targets.[16] Camera calibration procedures have been completed using photomodeler calibration module. A special test plate has been used for the calibration. Eight photographs taken for the calibration test plate and transferred calibration module and parameters calculated. Root mean square (RMS) residual was the 0.116628 pixel for camera calibration. The calculated camera parameters of the HP 735 digital camera were as follows:

focal length = 16.8090 principal point coordinates $x =$ 2.6373 principal point coordinates $y = 2.2670$ distortion parameters are $k_1 = 1269 \times 10^{-3}$, $k_2 = 1860 \times 10^{-5}$, $p_1 = -4203 \times 10^{-5}$, and $p_2 = 1722 \times 10^{-5}$.

Where k_1 and k_2 are first and second order of radial distortion coefficients, respectively. p_1 and p_2 are tangential distortion coefficients.

All photographs, measured coordinate values, and camera calibration parameters were transferred to photomodeler software.

With this software, the photogrammetric adjustment and evaluation process were completed. Errors were obtained in the adjustment process like below.



The whole 3D model of the Timras doline was obtained using software capabilities and data collected in field studies (Fig. 6).

Soil classification, limestone, and other important geological details have been measured only using photographs. All measurements were accomplished in a 3D coordinate system. All measured details were transferred to other formats such as DFX, VRML, and geological maps of the whole doline were produced (Fig. 7). All photogrammetric evaluation procedures were completed in 1 day.

RESULTS AND DISCUSSION

Some geological formations identified as a geological cultural heritage should be monitored continuously and periodically. However, most are located in places such as steep cliffs and volcanic and landslide-prone areas; in other words, unreachable and untouchable places. Thus, it may be too risky to undertake measurement.

In this study, a 3D map of the Timras doline was obtained using the close range photogrammetric method. All geological

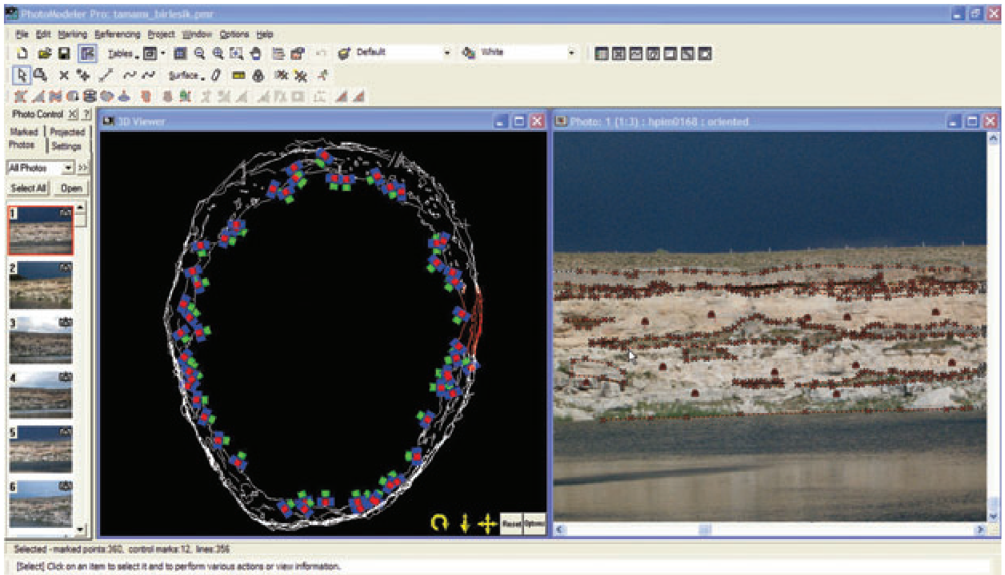


Fig. 5: Location of the cameras

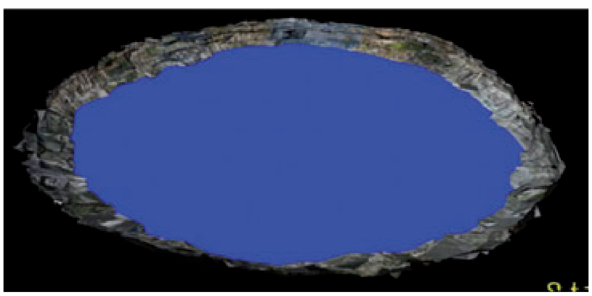


Fig. 6: 3D model of Timras doline

layers were determined by the geologists and a 3D geological layer map was obtained. All places, even unreachable areas, can be measured directly from photographs. With close range photogrammetry, large and risky areas can be measured in detail. These kinds of studies can be completed, depending on the dimensions of the study area, in a few days. Field and office processes in this study completed in 2 days.

It is not possible to measure inaccessible geological features in many positions. But close range photogrammetric techniques use only photographs to make measurements. So, all geological features that are large and risky areas can be measured accurately and safely. Many traditional methods cannot be used to measure all details or measurement and field studies can be much more along time. But according to photogrammetric techniques, the measurement can be accomplished more easily, safely, accurately, and fast.

RMS error is 0.09 m for x, y, z coordinates. Accuracy and feasibility according to traditional techniques is quite reasonable.

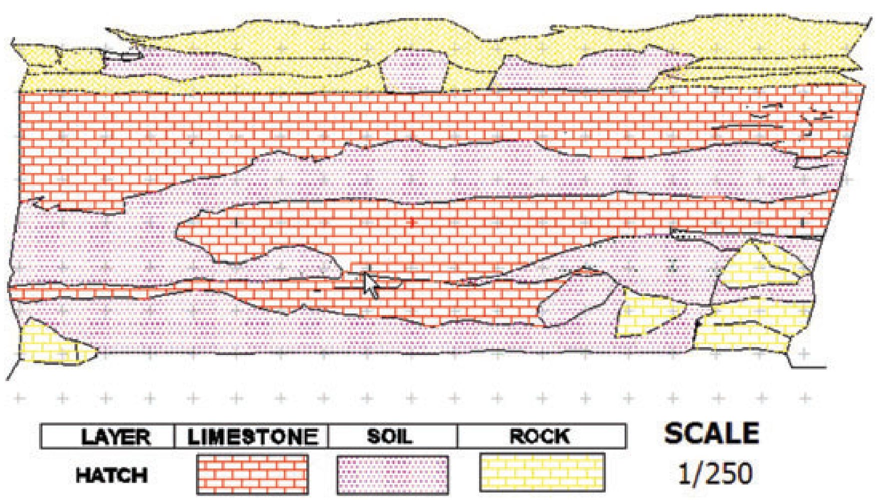


Fig. 7: A cross-section of Timras doline

Actually, this technique is more superior according to traditional techniques. It is not possible to measure inaccesible geological features in many conditions. But in this technique, only photographs are used to make measurements. So, all features can be measured accurately and safely.

CONCLUSIONS

In this study, the tectonic Timras doline geological maps were successfully obtained using digital close range photogrammetric techniques. This method is more reliable, faster, more accurate, and much safer. Accurate dimensions of different aspects including depth, width, slope, cracks, and various kinds of required details can be measured and used as geological inputs to obtain 3D geological maps. Furthermore, many dangerous places cannot be accurately measured by classical methods and photogrammetric methods can be safely used in these situations. Nowadays, generally, digital close range photogrammetry is applied due to cost advantages over conventional measurement techniques. First, taking photos is quite cheap and the labor costs are lower as well. In terrestrial measurement usually only two people are needed, because only the GCP have to be signalized and measured in the terrain by geodetic methods. Photogrammetric processing itself can be done by one person. The working time of the field study is also very short in comparison to other classical methods. In addition to these advantages, the 3D models which are obtained can be used for settlement planning. Furthermore, the models can provide information that enables the preservation of geological heritage and can contribute to the development of geotourism.

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