

PHOTOGRAMMETRIC MAPPING OF MEDITERRANEAN DEFENSE STRUCTURES USING AN AMATEUR DIGITAL CAMERA, GPS AND THEODOLITE.

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ABSTRACT

This work deals with the precise mapping of external faces of a structure called Tekes within the Medieval castle of Mytilene, Greece. The methodology using GPS and theodolite angle measurements to establish control on the faces of the structure are well described. Calibration procedures for an amateur digital camera which is used to make stereo photographs are presented. Final results of Tekes structure Photogrammetric mapping and analysis of the accuracy are documented and presented.

INTRODUCTION

This work is a part of a Euromed Heritage “Defense Systems on the Mediterranean Coasts” (DSMC), project financed by European Union and it is part of an effort of scientific research on the preservation of the cultural heritage in the countries of the Mediterranean Basin. For this reason, in the framework of this (DSMC) project, as one of its many research actions, it was decided to document digitally a defense structure and present the results in a Training Course organized by the University of the Aegean with the kind help of the 14th Ephorate of the Greek Byzantine and Post Byzantine Antiquities Service of Greek Ministry of Culture, in order to transfer the new tendencies in digital documentation (especially the use of the GIS – GPS and Photogrammetry) in all the partners from MEDA countries which participate in this project, and simultaneously to transfer knowledge from partners of MEDA countries with reach experience on this scientific field to all the other partners of the project. For this reason a training course was held in Greece (Mytilini, Lesbos) in June 2005 in the facilities of the University of the Aegean with the participation of trainers from Greece, and of trainees from all the countries which participate in the DSMC project. To provide modern innovative and state of the art ways on the preservation of the cultural heritage, it was decided to combine photogrammetry for detail digital recording of a defense structure together with theodolite measurements to establish an accurate framework as a reference system as well as GPS to establish a reference datum.

Mapping of historical Monuments for preservation requires precision in order to be able to make a detail recording of the elements of the structure form and size of stones, as well as, relations between them and distances). This process allows creation of documented maps showing deteriorations and cracks, which probably have resulted from seismic loads or soil settlements, or even from atmospheric pollution (phenomenon of acid rain etc.), which alters texture of structural material depending on its porosity. Traditional methods of such mapping require more time and specialized effort, in order to map one by one stone of the Monument. However, photogrammetric mapping could do the job with higher precision, minimizing time, and limiting costs of work.

Photogrammetric measurements tend to eliminate ground surveys (Hatzopoulos J., 1985) in an effort to minimize costs while maintaining the accuracy and quality of measurements. The main advantage of photogrammetry to maintain accuracy standards is redundancy and proper geometric configuration. Both of those advantages require taking a large number of photographs to increase redundancy and proper location of camera stations to achieve strong geometry with converged photography. This kind of arrangement is suitable for many

applications especially for architectural structures which have ordered elements in horizontal and vertical directions. However, complicated structures such as a medieval castle expose a lot of detail which has little or no order and referencing and / or measuring many images results to an increase of costs problem. On the other hand stereo or near stereo exposure of just a pair of photographs is enough to cover one of the faces of a structure. However, more photographs can be taken to choose from without any additional cost when using a digital camera. Another consideration of defense structures is the area of their expansion which is relatively large and complicated with large elevation differences. This analysis helps to adopt a combined methodological approach (Zhao, H., and R. Shibasaki, 2003) which takes advantage of modern technologies such as GPS as well as, older technology such as theodolite total station. Such approach uses GPS to establish a reference system and theodolite total station to establish a densified ground control network as well as a number of control targets on all faces of the structure to be covered by a near stereo pair of photographs. The process is applied in a structure named tekes located within the castle of Mytilene.

CASTLE OF MYTILENE – TEKES STRUCTURE

The Castle of Mytilene, lies on east part of the city of Mytilene, directly opposite to Asia Minor and was built on an islet separated from the mainland of Lesbos. It has been grown in the north-south direction and occupies an area of 6 hectares. It has been developed in three levels (Upper, Middle and Lower Castle level) and it was occupied by residents from Byzantine period, until modern times. When Mytilene was captured by Turks in 1462, the Castle was strengthened by the addition of a new fortification wall and it was enriched with new building complexes, inside the wall, thus covering increased utilitarian needs.

A general view of the area of the castle of Mytilene is given in Figure 1 and Tekes structure is located near the center of the area.

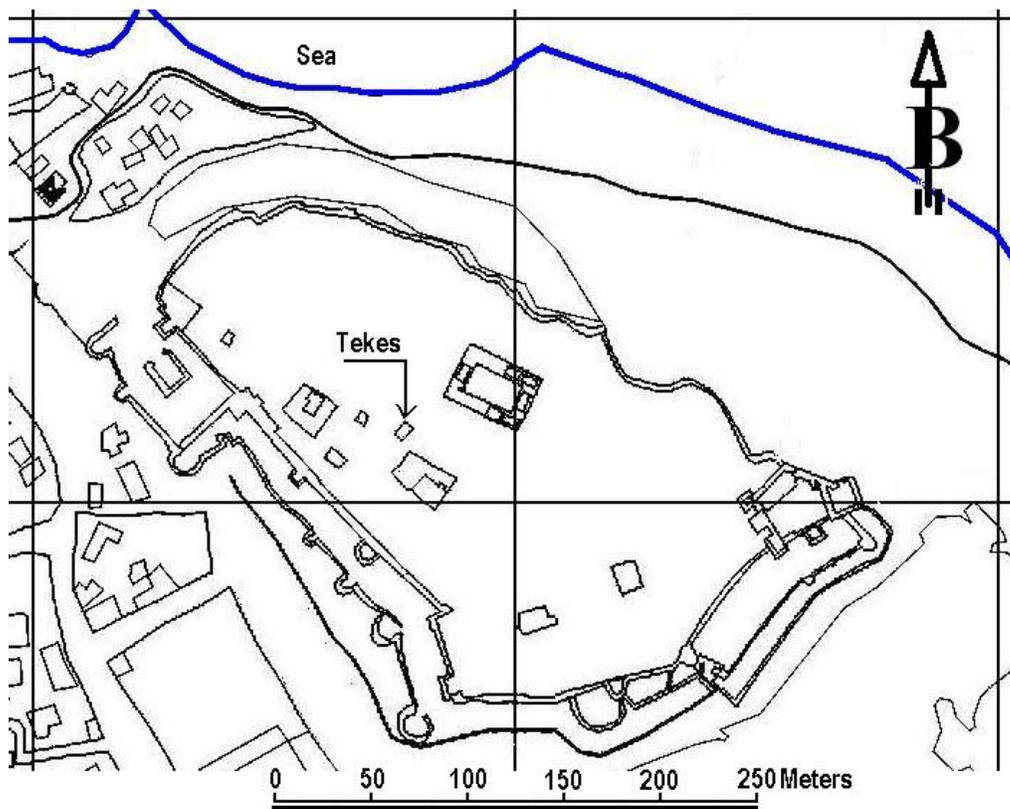


Figure 1. Castle of Mytilene (Greece) and Tekes structure

Further more Tekes of Mytilene castle, is found North east of Mendrese', the Turkish religious seminary and precisely against the ammunition building, in Middle Castle level. It is a building of religious character. Teke buildings were identical to Ottoman monasteries occupied by Muslim monks – cells of Muslim departurers.

The particular building has small dimensions, single room, with semicircular openings located all around its stone walls. It is a building covered by a dome and the plaster covered internal dome is supported by hemispherical drums. Externally the dome is surrounded by octagon cornice, of similar technotropy with that of neighbouring Mendrese'.

Typological elements and the structural material used, place with enough safety, the building in the same time period with that of Mendrese', which is in same group to whom they are members of.

There is no reference to any reference - source, but at compared with Mendrese, it is dated in 16th Century a. D. This building was constructed during kingship of sultan Bayezid II, by the big admiral of Ottoman fleet Hayreddin Easter, with terminus postquem 1533 (his chronology of nomination in the mentioned rank) - D. N. Karydis, M. Kiel, 2000.

The present condition of the Monument is villain and requires interventions of maintenance and fixing. The first stage for a restoration study is to make a detail map using new technologies such as photogrammetry so that to record and render analytically the structural elements and their deteriorations.

THEODOLITE AND GPS SURVEYS

Theodolite surveys were performed to establish a control point traverse K_1, K_2, K_3, K_4 (see Fig. 2) on the ground and at the same time those points were used to measure control targets on the structure. As Fig. 2 indicates each face on the tekas structure was viewed by two theodolite stations in order to determine the control targets by intersection. Intersection has chosen as a method which works with angular measurements only which require precise pointing at the center of the target. On the other hand EDM survey measurements on retro-reflective targets

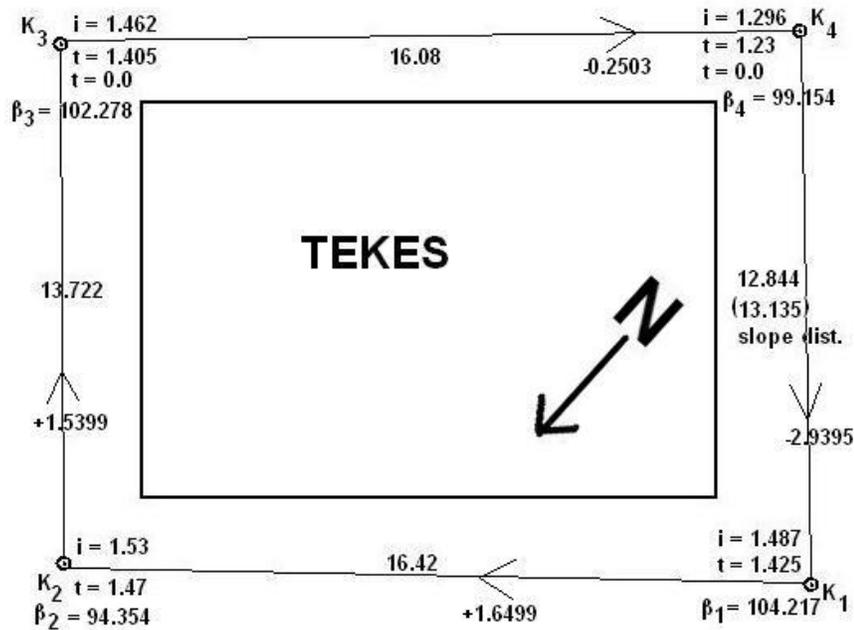


Figure 2. Theodolite 3D traverse surveys

located on the wall do not guarantee precise centering on the target. The classical 3D intersection problem is illustrated in Fig 3 where points A, B (in this particular case are traverse points) are known in 3D space with their X, Y, Z, coordinates. Zenith angles V_A, V_B and horizontal angles H_A, H_B have been measured by theodolite. Horizontal distance between A and B can be computed from CoGo formulas:

$$\begin{aligned} Z_{AC} &= Z_A + DZ_{AC} = Z_A + b/\tan(V_A) \\ Z_{BC} &= Z_B + DZ_{BC} = Z_B + a/\tan(V_B) \end{aligned} \quad (6)$$

$$\text{And} \quad Z_c = \frac{Z_{AC} + Z_{BC}}{2} \quad (7)$$

Using 3D intersection measurements about 50 retro reflective targets were measured on the structure as shown in Fig. 4. The error computed from the average Z elevations as shown in Equation (7) was found about 0.5 mm. In Fig. 4 is also illustrated the approximate location of the camera stations which were arranged to cover the entire structure with four near stereo pairs of photographs. Each pair of photographs had a convergence angle with its baseline of about 7 degrees to achieve a better base to height ratio.

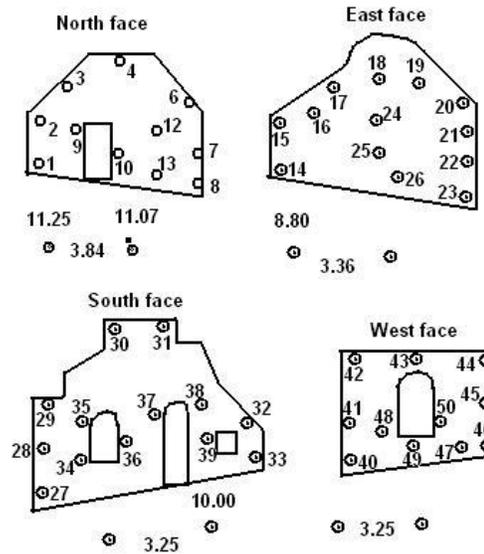


Figure 4. Sketch showing retro reflective targets in their relative position on the structure.

Theodolite surveys were performed using four tripods in corresponding traverse stations and using tribraches to carry the theodolite from one station to the next thus avoiding centering errors. The total time spend to do all traverse measurements and all control target measurements was about three hours.

Theodolite surveys of control targets are usually used by architects (Kakouros, D., 2004) by measuring angles and distances to the structure. Distances are measured by laser beams, which gives satisfactory results but does not have accurate pointing to the target as compared to the three dimensional intersection and it does not have redundant measurements to assess the precision.

Table 1: Coordinates of control site and stations K2 and K4

| Station ID | Easting (m) | Std Error (m) | Northing (m) | Std Error (m) | Ortho Ht (m) | Std Error (m) |
|------------|-------------|---------------|--------------|---------------|--------------|---------------|
| KAST | 721509.060 | 0.000 | 4331888.670 | 0.000 | 62.350 | 0.000 |
| K4 | 721359.367 | 0.001 | 4331993.256 | 0.002 | 40.867 | 0.002 |
| K2 | 721361.197 | 0.001 | 4332014.705 | 0.001 | 39.648 | 0.001 |

Table 2: Vectors' length, number of satellites and PDOP during survey

| From - To | Length (m) | Std Error (m) | SVs | PDOP |
|-----------|------------|---------------|-----|------|
| KAST - K2 | 195.574 | 0.002 | 7 | 1.9 |
| KAST - K4 | 183.834 | 0.003 | 8 | 1.3 |

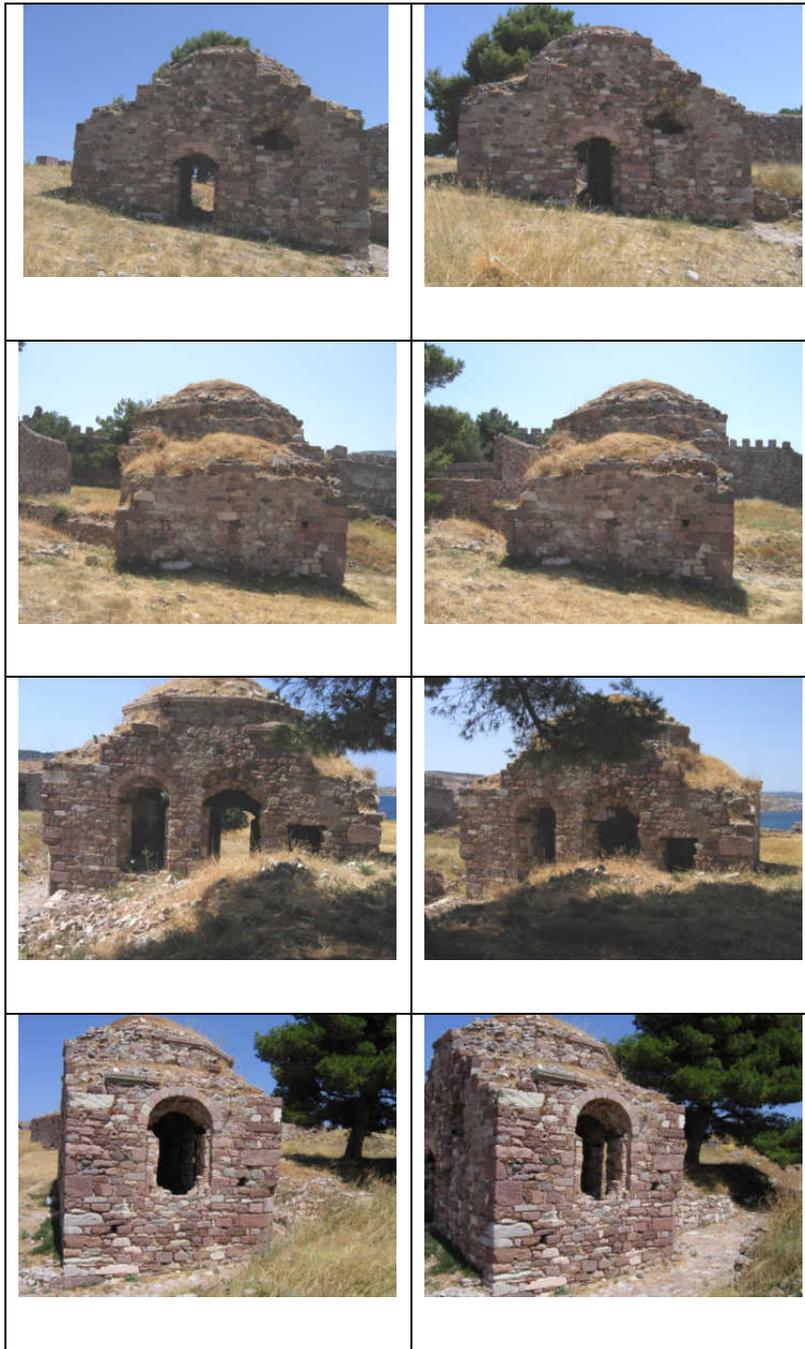


Figure 5. Near - stereo pairs of photographs to cover all faces of Tekes structure.

Traverse stations K_2 and K_4 as shown in Fig. 2 were also occupied by DGPS receivers and their coordinates were determined into the Hellenic Geodetic Reference System – 1987 (HGRS87). The stations K_2 and K_4 were tied to a survey monument with known fixed coordinates approximately 200 m away. In order to perform this survey a conventional total station Promark2 by Ashtech was used. One station was installed in control point while the other was placed in stations K_2 and K_4 which resulted in 2 vectors (delta positions). The raw data collected from receivers processed with Ashtech Solutions software in order to determine the differential relationship between the sites

occupied during data collection. Table 1 shows the results from raw data processing and the standard error of the final coordinates for the two rover stations and table 2 shows the resulted vectors. The desired accuracy for this survey was horizontal 0.003m + 1ppm and vertical 0.005m + 1ppm and was achieved.

ACQUISITION AND MEASUREMENTS OF PHOTOGRAPHS

The photographs were taken by a Canon Power Shot A95 digital amateur camera. Digital cameras for similar measurements and their performance have been reported by several authors such as: Li, J., M. Chapman & H. Ruther, 2005, Habib, A., M. Morgan, 2005. This camera used in this project was calibrated using a control field composed of retro - reflective targets which was also measured by theodolite with an estimated accuracy in elevation using equation (7) of 0.5 mm. Retro - reflective targets were underexposed and measurements were made automatically by Australis software which has been developed by University of Melbourne Australia. It was used a fixed focusing distance at infinity. The final results of camera calibration (Fraser, C., 1997) are shown in Table 3.

Eight near stereo pairs of photographs were taken as shown in Fig. 5. This configuration was chosen to be able to have about same view of the structure from either photograph and at the same time maintain a reasonable base to height ratio. The photographs were oriented and detail was measured using the EOS Photomodeler Pro software. The control points used for orientation were carrying a uniform reference system and during the measurements no noticeable y – parallax was found. Detail mapping of individual elements of the structure were measured with an estimated accuracy of 1.5 cm.

Three dimensional data were also obtained for any point covered by corresponding pair of photographs and they were directly referenced to same coordinate system as it was established by GPS. Results from photogrammetric three dimensional measurements using the EOS Photomodeler Pro software, are shown in Figure 6. Consequently detail and textures from the faces of the structure were obtained by crating orthophotos (Baltasvias, E., 1996) and using the EOS Photomodeler Pro software. Orthophotos of all faces of the structure are shown in Figures 7, 8, 9 and 10.

Table 3 Calibration results of Australis software

| Camera Variable | Initial Value | Total Adjustment | Final Value | Initial Std. Error | Final Std. Error |
|-----------------|---------------|------------------|---------------|--------------------|------------------|
| C | 36.2500 | 0.09616 | 36.3462 | 1.0e-002 | 1.432e-002 |
| XP | 0.0109 | 0.00153 | 0.0124 | 1.9e-003 | 3.181e-003 |
| YP | -0.0031 | -0.00094 | -0.0041 | 1.9e-003 | 3.231e-003 |
| K1 | -2.20520e-004 | 3.219e-004 | 1.01361e-004 | 7.9e-006 | 7.230e-007 |
| K2 | 2.21700e-006 | -2.189e-006 | 2.79763e-008 | 9.0e-008 | 4.913e-009 |
| K3 | -4.66320e-009 | 4.469e-009 | -1.94559e-010 | 2.5e-010 | 9.838e-012 |
| P1 | -8.69490e-005 | 1.157e-004 | 2.87072e-005 | 6.8e-006 | 1.300e-006 |
| P2 | 2.36980e-005 | -5.378e-005 | -3.00865e-005 | 1.0e-005 | 1.237e-006 |
| B1 | 0.00000e+000 | -9.446e-003 | -9.44580e-003 | 1.0e+003 | 4.957e-004 |
| B2 | 0.00000e+000 | 1.642e-003 | 1.64184e-003 | 1.0e+003 | 2.710e-004 |

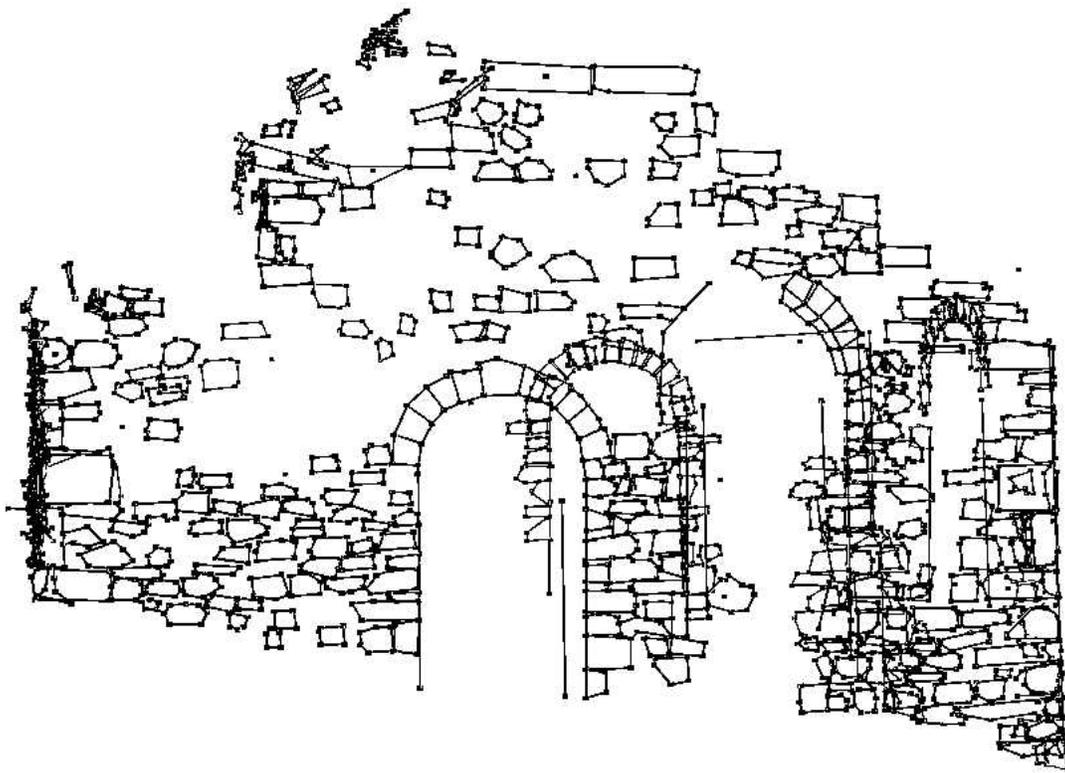


Figure 6. Three dimensional perspective view of digitized detail on the structure.



Figure 7. Orthophoto of the North face



Figure 8. Orthophoto of the South face



Figure 9. Orthophoto of the East face

A careful study of the orthophotos could reveal the way this structure was constructed, if individual elements were levelled, etc. Inspection also of the structure can be done to detect cracks and other damages and estimate precisely their location magnitude and orientation. This particular structure and other structures in the same area during construction were using elements from ruins of ancient structures such as temples, theatres etc.



Figure 10. Orthophoto of the West face

CONCLUSIONS

This project has shown that combined photogrammetric measurements with Theodolite surveys are perfectly fitted to provide integrated mapping for historical buildings and related defence structures. GPS measurements facilitate to establish a global reference system based on state plane coordinates. Three dimensional intersection using angular observations provides a better control over accuracy in this particular project better than half of a millimetre. Photogrammetry has also the advantage over other methods to be of low cost method by using a calibrated amateur digital camera and appropriate low cost software, it is an accurate method and provides a variety of products such as the photographs themselves as a permanent record, three dimensional data on all parts of the structure covered in at least a pair of photographs and also providing orthophotography to any surface of the structure.

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