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# Photogrammetry for Archaeological Documentation and Cultural Heritage Conservation

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## 1. Introduction

Photogrammetry is the art and science of deriving accurate 3-D metric and descriptive object information from multiple analogue and digital images. Recently, there has been an increasing interest in utilizing imagery in different fields such as archaeology, architecture, mechanical inspection, and surgery. Photogrammetry is concerned with deriving measurements of the size, shape, position and texture of objects from measurements made on photographs. In its simplest form, a pair of overlapping photographs is used to create a three-dimensional model, with the use of appropriate instrumentation can yield quantifiable dimensions of the object. Traditionally, these dimensions were represented on maps and plans, either as elevations, facades and/or contours. The use of photogrammetry as a tool to aid in the documentation of cultural heritage has a long history, and is well established as a measurement science. Recent advances in the science make the techniques much more flexible in their application and present new opportunities in the representation of monuments as diverse as aboriginal rock painting shelters, historically significant buildings and structures, and culturally significant precincts or districts.

The archaeological heritage constitutes the basic record of past human activities. Its protection and proper management is therefore essential to enable archaeologists and other scholars to study and interpret it for the benefit of present and future generations. In this chapter, Geomatics techniques will be used for archaeological documentation of one of the most important sites in Jordan (Aqaba Fort). The city of Aqaba, Jordan is located along the northern shore of the Gulf Aqaba with a central coordinate of 29.5° N 35.0° E . The port in Aqaba provides the country of Jordan with their only marine site for the import and export of goods. It is also considered as one of the most popular tourist resort in Jordan and the Middle East where warm climate, beaches, and coral reefs. Aqaba is connected to the urban centres of Jordan to the north by two highway. There are overland border points to Eilat (5 km north) and Saudi Arabia (16 km south), and ferries connecting Jordan directly to Egypt. The 'Aqaba' is short of the old Arabic naming Aqaba Ayla, meaning 'Pass of Ayla'.

GIS will be used to create vector layers of the main architecture component of the fort. Photogrammetry will be employed to generate a digital elevation model and an Ortho-photo which can be used together to give an actual terrain view for the historical structure

while close range photogrammetry would show the three dimensional building with real coordinates and texture. As a result, stand alone application for one of the most popular archaeological sites in Jordan. Graphic user interface consist of three main items; Geographic Information System that include location using GPS, Landuse, Ortho-photo, Geology, Digital elevation Model and three dimensional model for the Aqaba fort using close range photogrammetry.

## 2. Historical background

The city of Aqaba, Jordan is located along the northern shore of the Gulf Aqaba with a central coordinate of  $29.5^{\circ}$  N  $35.0^{\circ}$  E, Figure 1. Aqaba established a special economic zone with reduced taxation. The port of Aqaba provides Jordan the only marine site for the import and export of good.

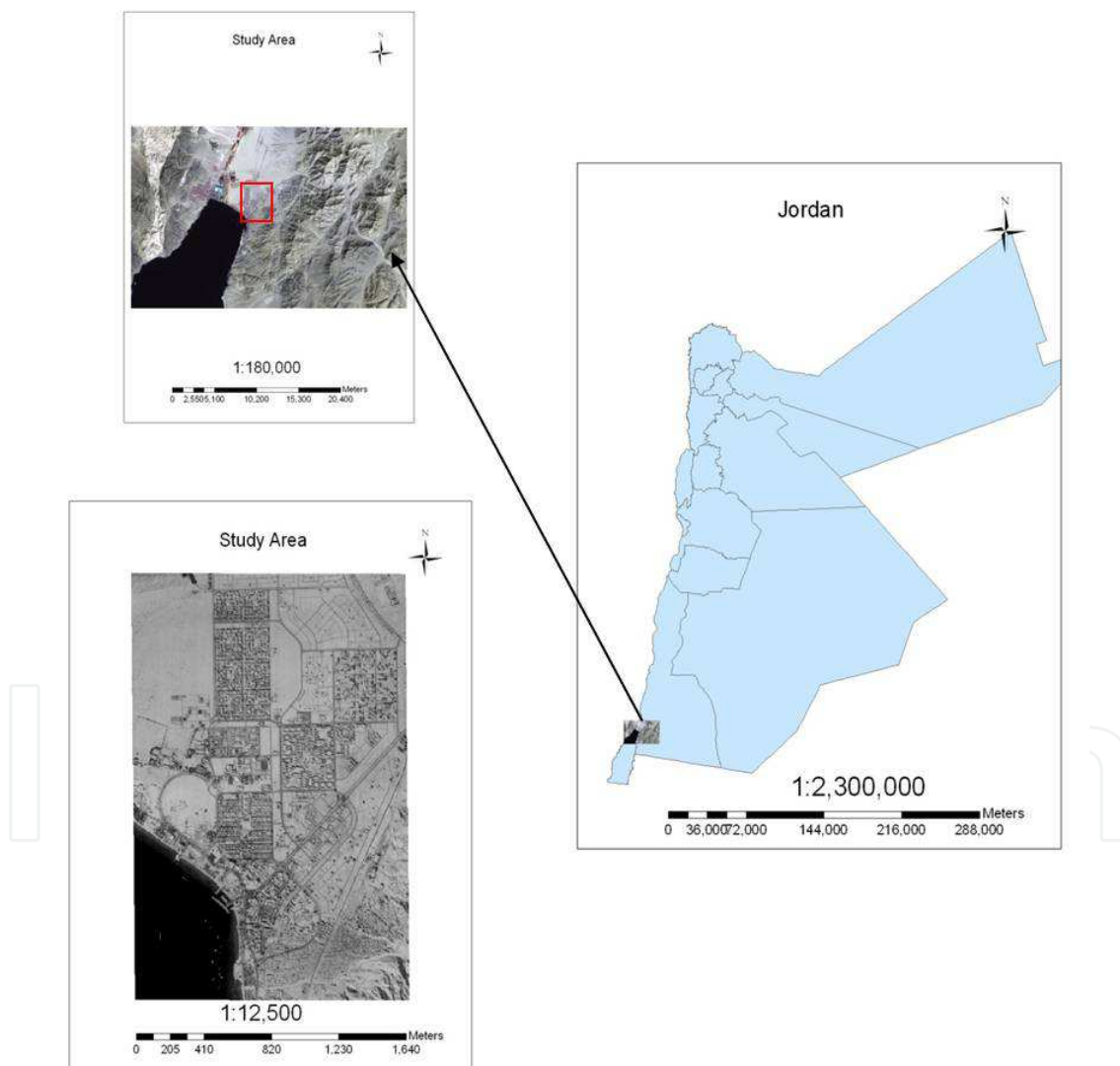


Fig. 1. Aerial photo of the study area.

Aqaba' is the short of the old Arabic naming Aqaba Ayla, meaning 'Pass of Ayla'. Aqaba is a coastal town with a population of 101,290 at year 2000.

The reason for building a fort on the shore was probably from the 13th century onwards connected with the involvement of the Mamluk sultans, in protecting the Egyptian pilgrimage to Holy cities of Arabia, When Ayla served as a stopping point for caravans. The castle, Figure 2 has the form of rectangle enclosure (56.5m by 58m). With towers projecting from the corners and a twin towered gatehouse. Ranged around the inside faces of the walls were rows of individual cells, arranged at two levels and evidently intended to provide accommodation for pilgrims. On the South wall stood a mosque, of which only the qibla wall and mihrab now survive. Aerial view of the Aqaba fort appear in Figure 3.



Fig. 2. Terrestrial photos for Aqaba fort.



Fig. 3. Aerial view of Aqaba fort.

### 3. Data collection

The data sources starts with Photogrammetric data that include terrestrial, aerial and satellite images; second, spatial (GIS) data that include maps, vectors files such as ground control points, and location of point events, lines (counter lines and roads).

### 3.1 Photogrammetric data

The photogrammetric data includes: stereo aerial photographs, satellite images , LANDSAT and Spot images and terrestrial images. Two main photogrammetric products, Ortho-photos and digital elevation models (DEMs). Figure 4 describe sample of aerial photos captured 2007 and have 1/6000 scale used in Aqaba city. These photos have the following properties: Photo scale: (1:6000), film format is (23x23) cm, overlap between the two photos equal 60%, Camera: Wild RC30 and Photography captured 2007.



Fig. 4. Aerial photo of the study area.

Sample of images for landsat 2000 shown in Figure 5 has been used as base for GIS layers.

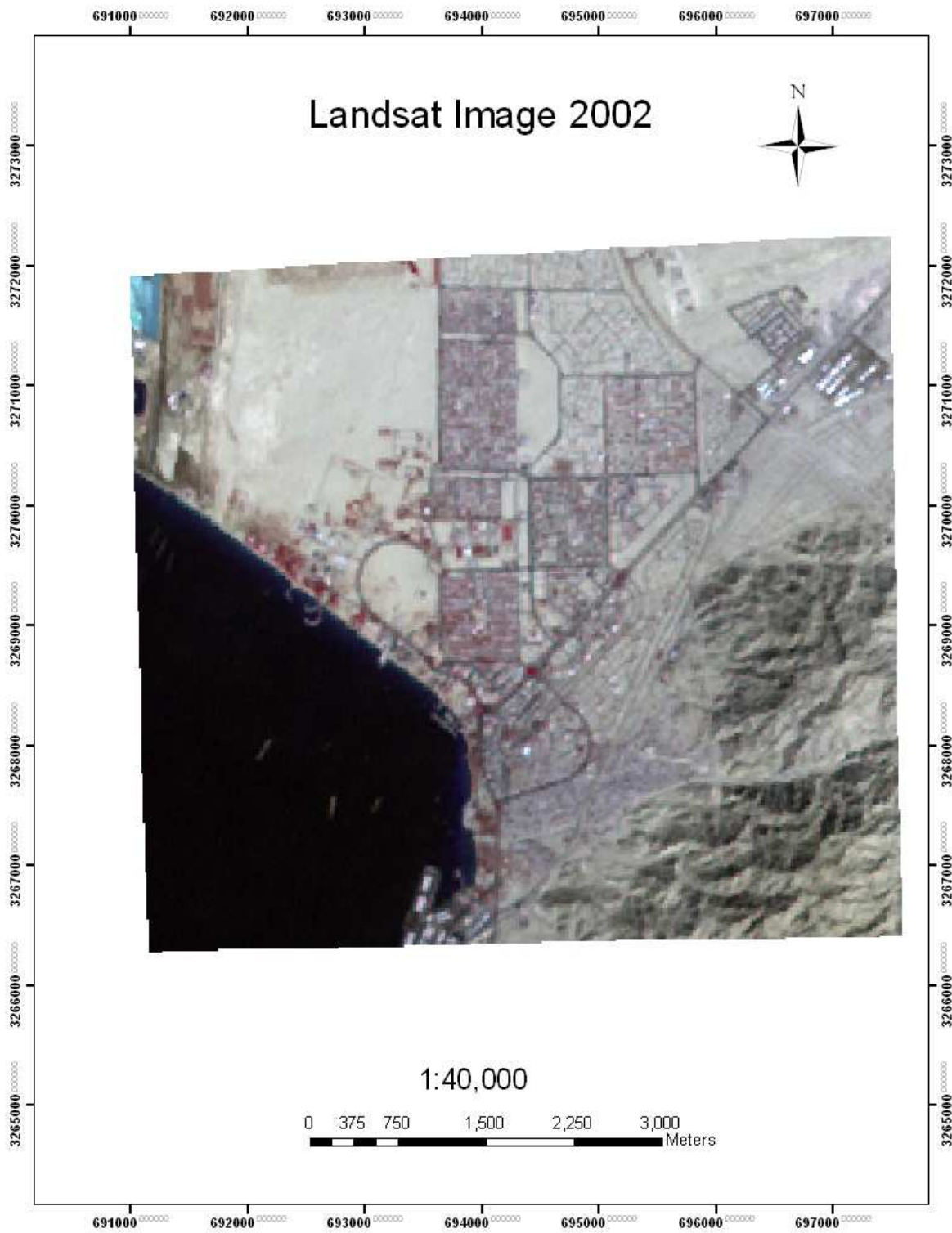


Fig. 5. LANDSAT 2000 image for the study area.

### 3.1.1 Terrestrial Images

Sample of photos with different angle of view captured for Aqaba appears in Figure 2. these images are used for building three dimensional model of front side of Aqaba fort.

### 3.2 Geospatial layers

Basically most of layers used in this area is digitized from ortho-photo, such as building, roads and trees. The scanned hard copy maps appears in Figure 6, was captured from the fort museum and originally prepared by university of Victoria and Jordan ministry of tourism and antiquities at 2000 and 2005.

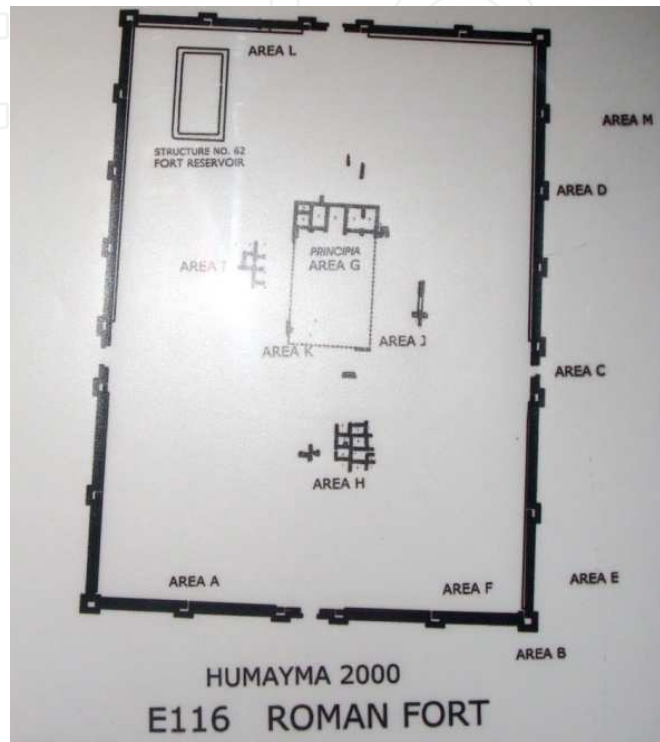


Fig. 6. Scanned hard copy maps for Aqaba fort.

5m Contour maps shown in figure 7, provided by Aqaba Special Economic Zone Authority has been used in this study.

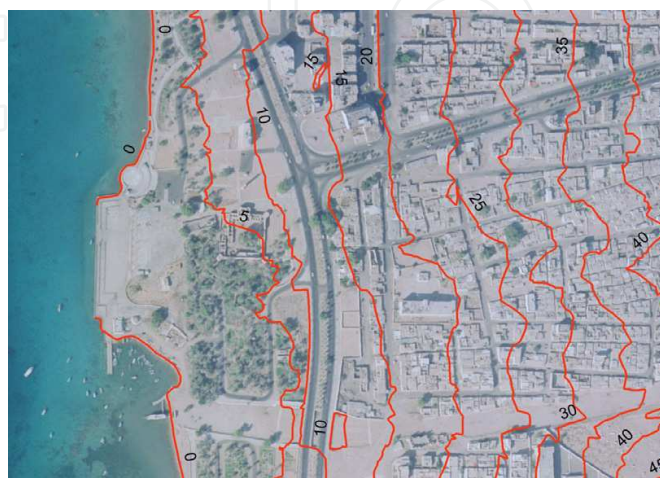


Fig. 7. Contour map overlay with Ortho-photo.

## 4. Data processing

Different stages are included in this section starting with GPS for ground control reference information, photogrammetric processing to generate ortho-photo and digital terrain model, followed by GIS processing that include scanning, geo-referencing layer designing, digitizing and finally generation of maps and 3D representation of the site.

### 4.1 Global positioning system

Terrestrial and Global positioning system (GPS) survey were required within this study mainly for three major purposes: GPS survey was used to produce ground control points needed for processing of all aerial photographs and satellite images covering the archaeological sites; GPS survey also provided check points used for quality control of the produced ortho-photos and digital maps; and finally terrestrial survey was used to provide control and check points for the close range photogrammetry works.

All GPS survey of the ground control points was performed in static mode with sessions 10 minutes to 1/2 hour. Check points collected with GPS were observed in Stop-and Go mode with usually 2 static reference receivers. The precision of a Stop-and Go GPS survey is about  $10\text{mm}+1\text{ppm}$  for post processed carrier phase observations.

The GPS field survey was processed using Ski-Pro and Leica GEO-Office software, while LisCAD Plus software was used for processing of the total station measurements. The following algorithm was followed in data processing: the coordinates of the reference stations (usually two) were obtained. The reference stations are points with known coordinates such as Ref BAU, the point at Al-Balqa' university or RAMO, which is one of the continuously operating reference stations of the International Terrestrial Reference Frame (ITRF). This point is closest to Jordan, its coordinates are published on the official site of the International GNSS Service (IGS). The raw GPS observations for this station or any other of the ITRF are also provided by GNSS Data Center (GDC). For sites located away of available control points the coordinates of new reference stations are computed via OPUS-Online Positioning User Service, a web base service provided by the National Geodetic Survey of the USA. The control station coordinates and the GPS observations (including ground control point and checkpoints) were then used in the processing, which includes baselines processing, least squares adjustment (when redundancy available) and export of the final coordinates. The coordinates of all ground control points are computed in WGS84 coordinate system, ITRF 1994 or 2000, available in form of geodetic (latitude, longitude and ellipsoidal height) and Cartesian coordinates (Geocentric X, Y and Z). In order to produce maps and use the same points as references for the terrestrial survey these coordinates are transformed onto mapping surface using Universal Transverse Mercator Projection- zone 36 and 37. Additional control points are established during the total station survey in form of traverses linked to the GPS control points. Reference stations and GPS ground control points shown in Figure 8.

### 4.2 Photogrammetric processing

With the advent of digital photogrammetry and image processing technology, photogrammetric recording of world heritage sites has rapidly increased (M. Ioannides et



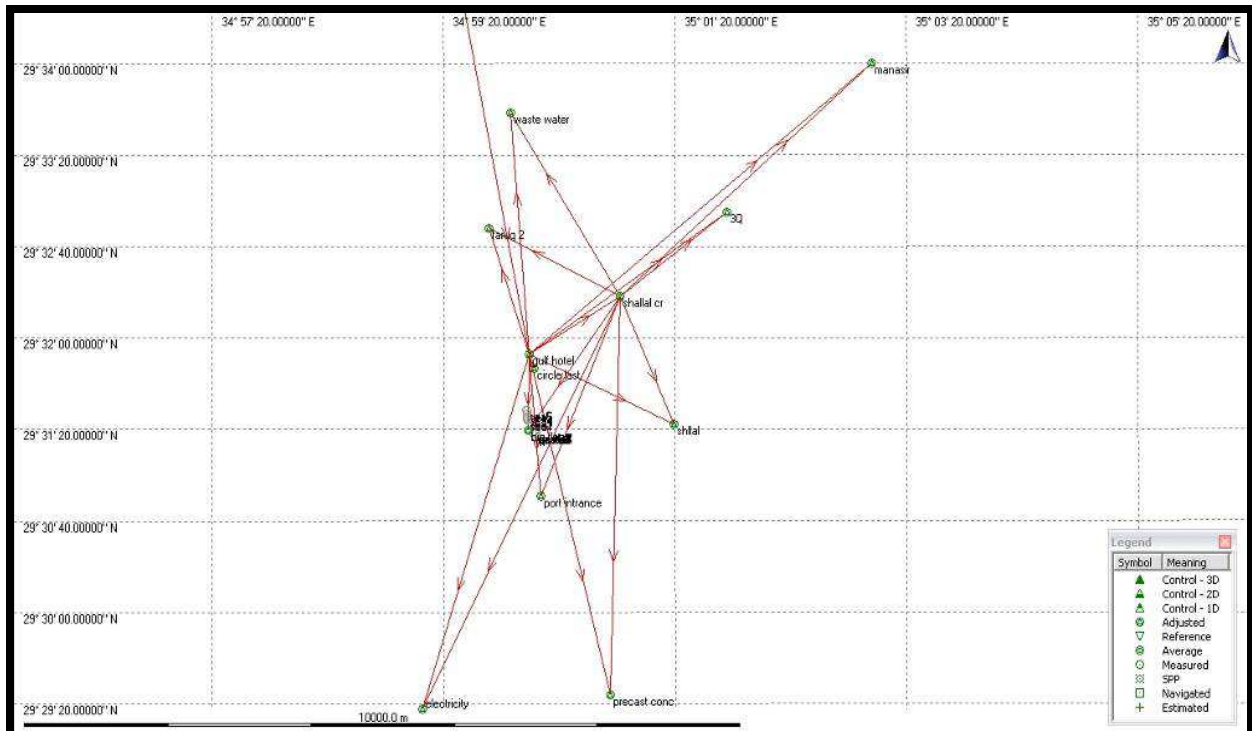


Fig. 8. Map for reference stations and GCP at Aqaba.

al.,2010). Digital object enhancement and 3D-modelling techniques are also possible and usually give clear presentation of heritage sites. They considerably enhance recognition of construction material, shape and area, and their spatial distribution, which is considered as one of the most difficult and time-consuming tasks for architects (Lerma et al., 2000). In summary, photogrammetry offers a rapid and accurate method of acquiring three-dimensional information regarding cultural monuments. In this paper photogrammetric processing used for three main productions; Digital Terrain Model (DTM), orthophoto and real three dimensional models using close range photogrammetry.

The basic problem in analytical photogrammetry is to mathematically relate the positions in space of imaged objects to the positions of their image points in the plane of the image, and vice versa, (Kubik, 1991). The most basic geometric concept utilized in developing solutions to this problem is the collinearity condition which is that the camera station, the image point, and the imaged object all lie on a straight line. collinearity equations ( mathematical model between image and ground coordinate) appear in the form where the image coordinates of an object are expressed as functions of the Interior Orientation Parameters(IOPs) and the Exterior Orientation Parameters(EOPs), and the space coordinates of the object, (Krishna et al., 2008 ).

Several methods can be applied to determine the parameters of the orientation of one, two or more photos. The orientation can be processed in steps (relative and absolute orientation) and simultaneous methods (bundle adjustments) that is available in a majority of software packages. For systems based on stereoscopic measurements, the stereomodel derives from a relative orientation. In this step, points coordinates are determined in an arbitrary coordinate system of the stereomodel. The determination of points in the object coordinate

system is done in a second step, known as absolute orientation, by applying a three-dimensional similarity transformation.

For the interior orientation, two sets of parameters have to be considered. The first one contains the geometric parameters of the camera: the principal distance and the coordinates of the principal point. The second set includes the parameters that describe the systematic errors (as distortions or film deformations), (Heuvel, 1999). At least 5 tie points, that appears in the overlap area of stereo pair, required to extract the three dimensional model from stereo pair. Connection of an aerial Photograph and its corresponding object space is performed by the (EOPs) of that image. These parameters establish the physical geometry of imaging sensor with respect to ground and describe the position and orientation of that sensor at the time of imaging. At least, two full ground control points and one vertical is needed to solve the EOPs based on three-dimensional similarity transformation (Samadzadegan et al., 2002).

In this study two digital aerial stereo photographs were used to extract the ground coordinates of tie points and sequentially building DTM and orthophoto. Bundle adjustment within Leica Photogrammetry Suite (LPS) software has been used for modeling and DEM generation. The software supports reading of data, manual or automatic GCP and tie points collection and geometric modeling of aerial Photograph based on collinearity equations.

For DTM generation, image correlation strategy was used for automatic extraction of the tie points. Moreover, adaptive method was used to generate a DTM with grid format, where the topographic nature of terrain was considered; Firstly a DTM file was created with 10 m post spacing to provide the whole project area with initial elevations of the terrain model where each post was edited to ground and saved. Then another DTM was built with 5 m post spacing, where improved representation of real terrain for 1:5000 photo-scales can be obtained. Finally, The Root Mean Square Error (RMSE) was used to describe the consistency between the generated DTM and GPS points. The error is determined using the least square regression method. This is called the residual error that measures the fit in elevation between GPS points and extracted DTM. Eight check points were used to calculate the RMSE. The RMSE was calculated and found to be 0.351 m. Figure 9 shows the DTM generated along for the study area where height ranges from 0 to 959 meter above mean sea level.

Next stage in photogrammetric processing is to generate an Ortho-photo as in Figure 10. Basically the Ortho-photo is a photograph transformed from perspective to orthogonal projection, or otherwise said, corrected for tilts and relief displacements. The produced DTM is to be used for Orthophoto generation. Regions that are not edited correctly in the DTM file appear on the Orthophoto as breaks and cuts in the region. These errors were removed by manual editing of the DTM based on visual inspections. Figure 10 shows the generated Orthophoto.

The last part in photogrammetric processing is the 3D modeling that deal with real representation of the features, shapes, and texture based on Close Range Photogrammetry. The principle of the 3D modeling is to give the features the same dimension and texture as reality (Wamg, Ahmad, 2002).

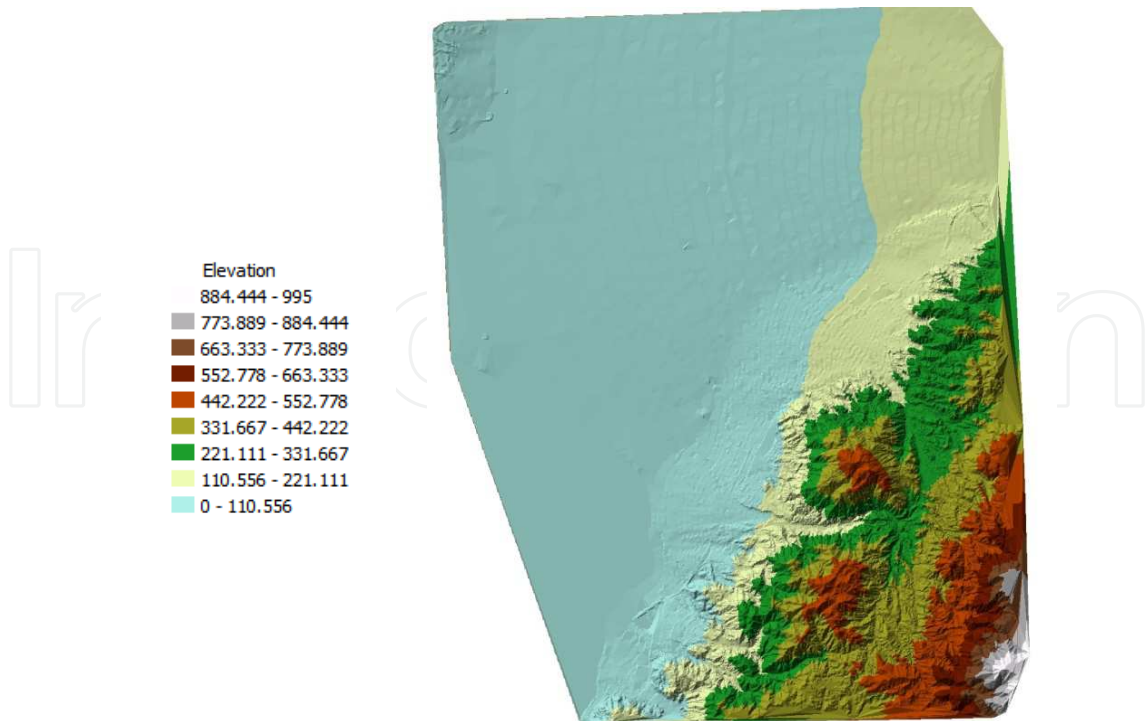


Fig. 9. Surface model for part of Aqaba area.

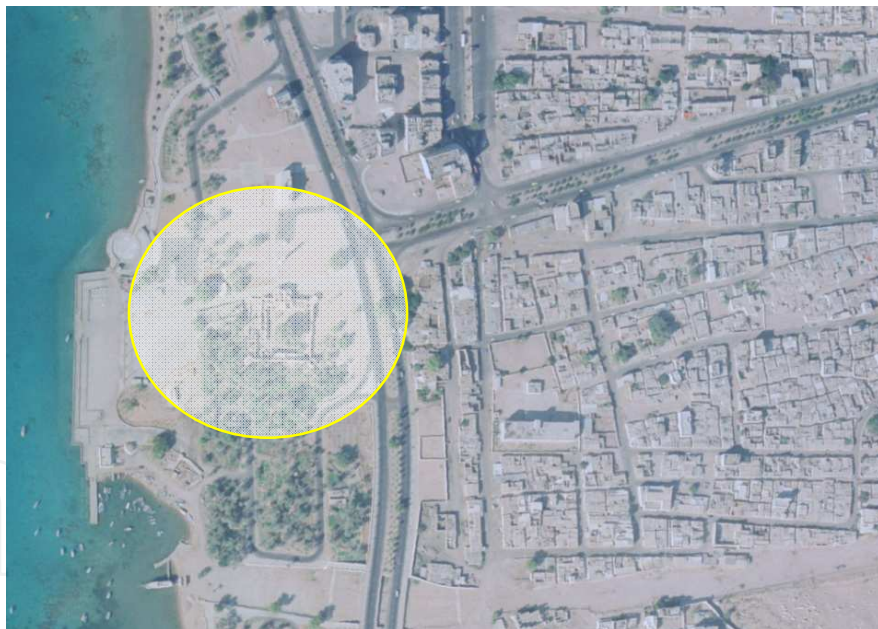


Fig. 10. Ortho-photo in Aqaba city with Aqaba Fort.

When using the photogrammetric techniques for recording and documenting the cultural heritage, the factors with impact on recording accuracy and archiving efficiency must be considered (Dallas et al., 2002): namely, metric characteristics of camera, imaging resolution and requirements of the bundle adjustment procedure. The mathematical model that incorporates self-calibration and bundle adjustment procedure for accurate estimation of the interior and exterior orientation parameters has been adopted. This is a necessary prerequisite for accurate and reliable 3D-reconstruction.

After estimating the interior orientation parameters of the camera, experiments are conducted based on real data to build a three dimensional model. For this purpose, the calibrated SONY DSC-F707 digital camera is used to capture convergent images at three different locations with 90o rotation around the Z-axis at each exposure station. An arbitrary datum is chosen as reference for the object space, where conjugate points are selected. These measurements are introduced into the bundle adjustment in order to estimate their grounds synchronize. Selection of the points was performed while considering the following issues:

1. Distribution of points. The measured points must be well distributed and must cover the whole objects under study.
2. Visibility of each point in two or more images. If the same points appear in larger number of images, the geometrical strength as well as the accuracy of three-dimensional coordinates will be improved.
3. Adequacy of selected points for the reconstruction of different shapes from an architectural point of view.

As shown in Figure 11, the three dimensional coordinates resulting from adjusting procedure are used to reconstruct 3D model for Aqaba fort that mentioned in Figure 2.

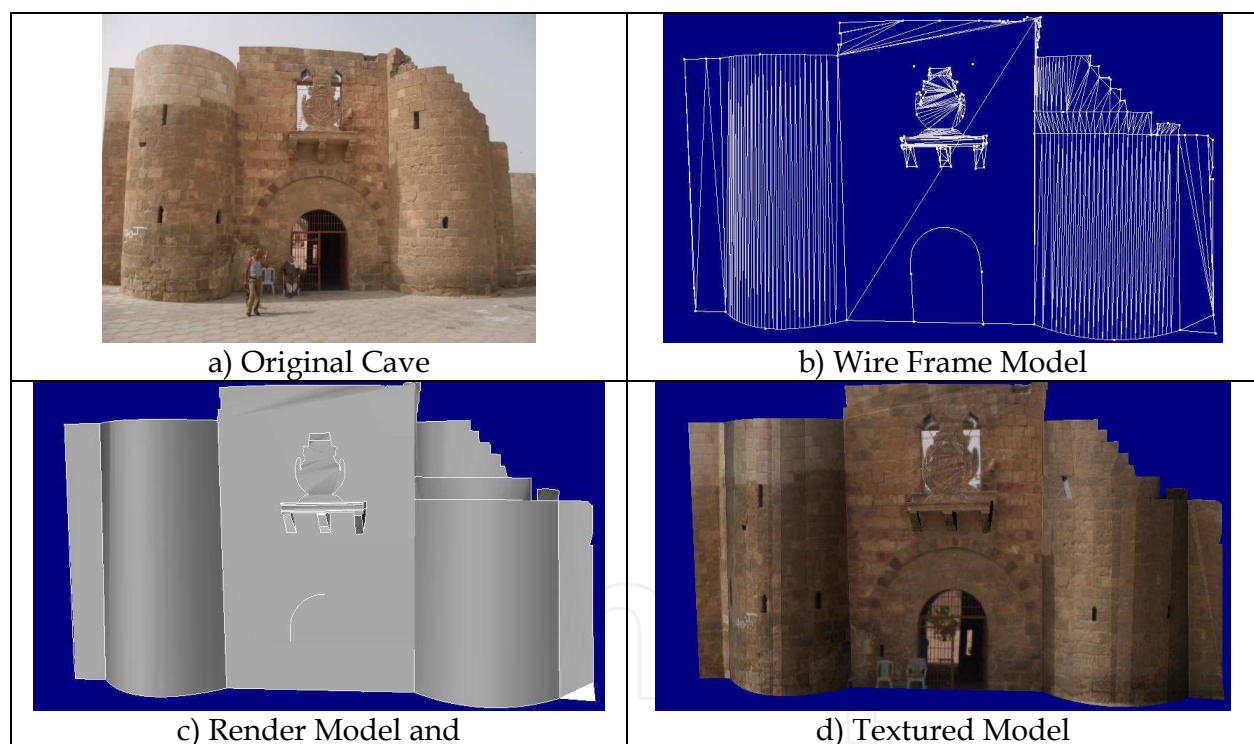


Fig. 11. Three Dimensional Model for the fort.

Surface rendering, which involves the generation of a 3D model with a real world surface texture, is constructed, Figure 11. That means, the surface textures are added to the 3D model surfaces to give a real world appearance to the displayed model. The 3D surface rendering is very important for the presentation of a ruined heritage sites where architects and renovation experts must have a realist view of the ruin for further inspiration (Ogleby 1999). Moreover, the 3D model can be digitally rotated to give a whole range of perspective views, (Habib et al., 2004)..

### 4.3 Geographic information system

A Geographic Information System is a collection of information technology, data, and procedures for collecting, storing, manipulating, analyzing, and presenting maps and descriptive information about features to be represented on the maps (William et al., 1995). Cultural heritage objects often have a very irregular complex geometry. Thus, a good digital reconstruction requires a very detailed 3D model with a lot of geometry elements. So there are two main requirements for the 3D GIS. The first is a support for the acquisition and handling of large amounts of complex and non-planar 3D geometry. The second is the visualization of these objects which consists of a lot of geometry elements (Wüst et al., 2004).

This study highlights the representation and integration of photogrammetric products, which illustrated in previous sections in geo-referenced maps and images where the huge database can be manipulated, managed, and visualized. The obvious and accurate geometric overlaying of these different data will be helpful and great support for interpretation and analysis of the results.

It should to be mentioned that diversity of superimpose data that can be represented in the GIS system include (Boundary Maps, Point Location of Archeological Sites, Transportation Layer, Hydrological Maps, Digital Elevation Model, Aerial Images (Ortho-rectified), Satellite Images, Land Classification Image, Aquifer Profiles and Geology of the Area). All these layers are associated with database and descriptive attributes. The system should to be designed in a way that allow an easy and flexible updating of the new coming database. Figure 12 shows digitized features (Building, Streets, Parcels...) in GIS dropped over the digital elevation model.



Fig. 12. 3D image with Digitized GIS features.

Figure 13 shows the terrain in three dimensional representations where figure 14 shows LANDSAT image dropped over elevation model.

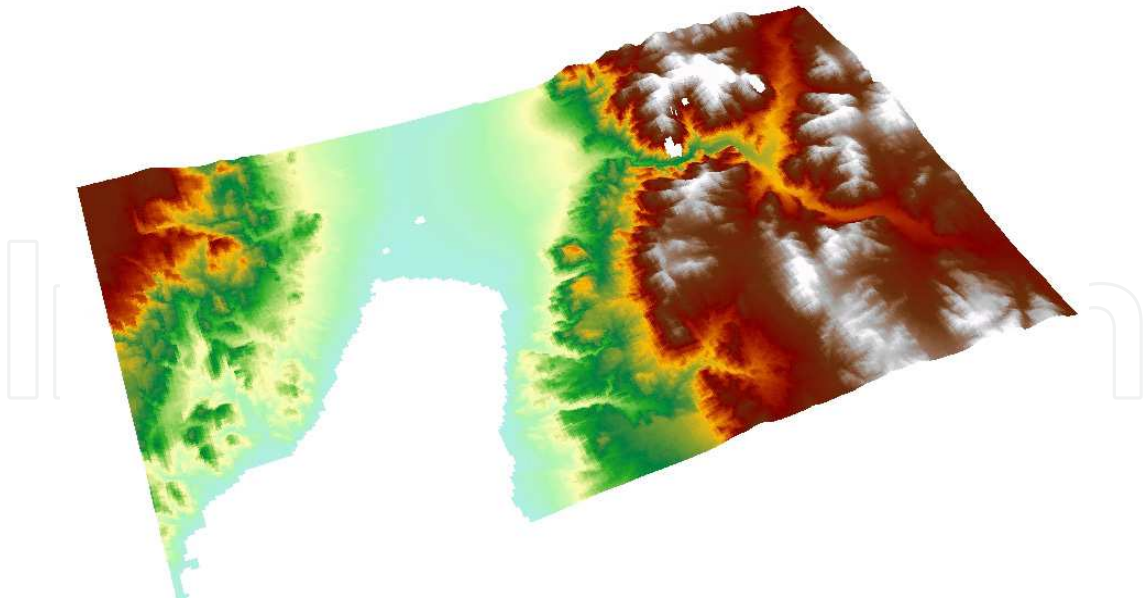


Fig. 13. Digital Elevation Model (DEM).

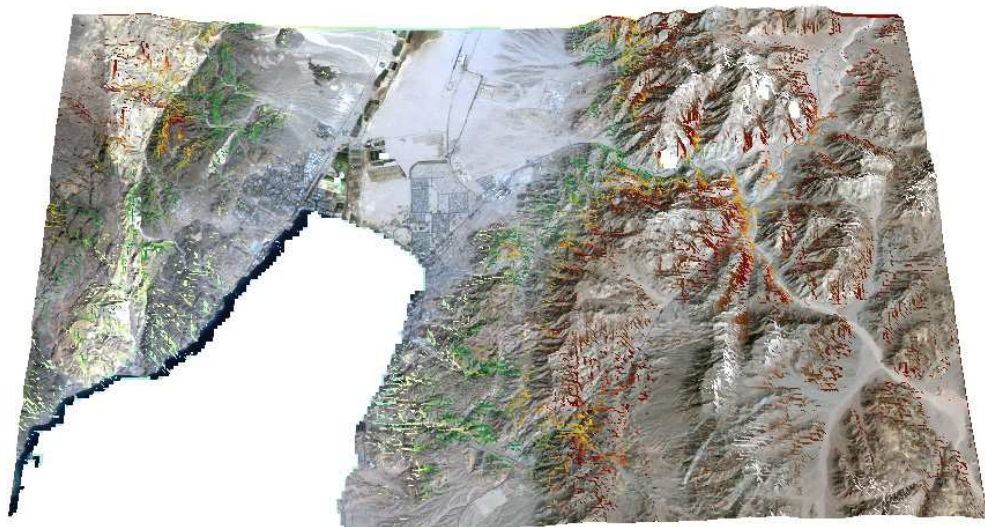


Fig. 14. LANDSAT Dropped On (DEM).

## 5. Final remarks and future work

In this study, we have presented different steps that can be used for archaeological documentation of Aqaba fort. The feasibility of integration between different sciences has been explored. Photogrammetric Techniques were used to emphasis on the identification of existing archeological sites in addition to generate map for tourism purposes where fair mapping of all historical objects can be conducted. Also, Aerial photographs Processing (stereo pair) in the study area was conducted where high resolution Orthophoto image produced in order to be used for measurement in GIS systems. Moreover, High resolution Digital Elevation Model was generated to grant details about the topography of the study area. Finally, 3D models of historical archeological structures in the fort was performed. During the generation of these models, requirements such as high geometric accuracy, availability of all details, and efficiency in the model size and photo realism have been considered. 3D models of historical

archeological structures in the fort area with actual texture were generated. These models are vital for fair preservation of details of the historical castle.

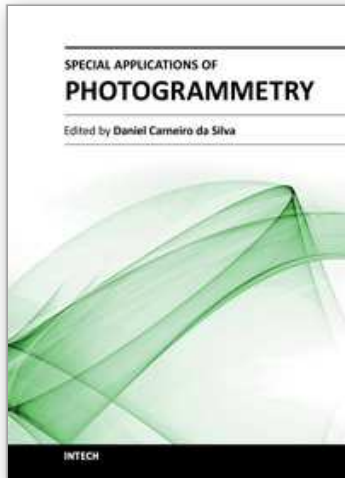
Finally, photogrammetric as well as vector layers results have been geometrically registered and presented in a system that enable better viewing, analyses and interpretation. consequently, 3D GIS Model that include was established and serve as basis for preservations or for interactive presentations of the Aqaba fort.

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## **Special Applications of Photogrammetry**

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Photogrammetry is widely accepted as one of the best surveying methods to acquire tridimensional data without direct contact with the object, but its high operational costs in equipment and personnel somewhat limit its application in mapping. However, with the development of digital photogrammetry in the 1990's, it was possible to introduce automated processes and reduce the personnel costs. In the following years, the cost of computer hardware, digital cameras and positioning sensors has been lowering, making photogrammetry more accessible to other engineering fields, such as architecture, archeology and health fields. This book shows the results of the work of researchers from different professional backgrounds, which evaluate the uses of photogrammetry, including issues of the data, processing, as well as the solutions developed for some surveying types that can be extended to many applications.

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