Construction of a Digital Landform Dataset at Kaman-Kalehöyük: Method Improvement by Automated Data Collection of Laser Range Finder

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ABSTRACT

Ground-based laser measurement of landforms is carried out in areas surrounding Kaman-Kalehöyük, using a handheld laser range finder (LRF) and Geographic Information System (GIS). The automated data collection of the LRF measurement with a personal computer and connection cable substantially reduces the cost of measurement time compared to manual data transportation. High-resolution topography data are then obtained in the study area as a Digital Elevation Model (DEM) and its derivatives such as contour lines, hillshade and slopes. The collected point dataset is also concatenated with those previously obtained, and a revised topographic map is obtained for the extensive area, from the DEM-derived contour lines and overlaying feature data of ground objects. The high-resolution topography data show that the shape of the tepe is polygonal rather than completely circular. Analyses of topographic cross sections and locations of surface water flow paths help to reveal landform characteristics around Kaman-Kalehöyük.

Keywords: Landform, Laser range finder, DEM, GIS, Kriging interpolation

INTRODUCTION

Spatial information of landforms, such as a topographic map, is fundamental for various field studies, because landforms often have significant effects on environmental processes and human activities. In 2005, Hayakawa and Kashima (2006) performed field measurements of topography in the northern and eastern areas around Kaman-Kalehöyük using a Laser Range Finder (LRF), and produced a topographic map not only as a paper sheet but also in a digital format. The measurement method was originally proposed by Hayakawa *et al*. (2007). However, the data conversion in the method was inefficient and sometimes problematic, because the LRF measurement data is transported manually, *i.e*., the coordinate (XYZ) values are hand written and entered into a computer via keyboard.

This paper illustrates an automated method of LRF data collection with a connection cable and portable tablet-style personal computer. First, topography data from the western and southern areas of Kaman-Kalehöyük were collected and a Digital Elevation Model (DEM) of the area was obtained in a relatively high resolution. Second, the obtained dataset was combined with the previous one by Hayakawa and Kashima (2006), giving an extensive topographic map around Kaman-Kalehöyük. Advantages of the automated method and some analyses of the obtained digital topography data were then demonstrated.

DATA COLLECTION USING LASER RANGE FINDER

This study uses a non-prism LRF (LaserAce 300 by Measurement Devices Ltd., UK) for the measurement of landforms. The LRF gives data of distance, horizontal angle and vertical angle in a measurement such that three-dimensional coordinates of a target point from a measurement point can be obtained. The maximum distance of measurement by the LRF is 300 m, but usually the measurable distance is less than 200 m depending on air conditions such as dust density and humidity. The accuracy of distance measurement is 0.1 m and the resolution is 0.01 m. The measurable range of vertical angle is ±80°, with an accuracy of 0.3° and a resolution of 0.1°. The horizontal angle, whose accuracy is less than 1° with a resolution of 0.1°, is given as an angle from magnetic north (0–359.9°).

The LRF is connected to a tablet-style personal computer, such that the measurement data in the LRF are directly imported to the PC. The data are received by a macro program built in Microsoft Excel.

Field measurements were performed by the author in August 2006. The target area was the southwestern area of Kaman-Kalehöyük (Fig. 1). The areas of the excavation trenches were not included because the focus of this study is on the overall characteristics of landforms in the area. Starting from the base point (longitude 33 °47'11.1''E, latitude 39°21'46.2''N, altitude 1069.6 m a.s.l [Hayakawa and Kashima 2006]), 21 measurement points were successively placed, whose location was measured from each previous measurement point using the LRF. The base point location is measured from the final measure point, so that the measure points are placed as a closed traverse. Point data of land surface morphology were measured from each measurement point using the LRF and connected tablet PC. In total, 1,432 points were collected in 3 hours. The approximate area of the data distribution is 90,000 m^2.

POST-PROCESSING OF FIELD DATA AND MAP CONSTRUCTION

Post-processing of the raw data obtained in the field survey was undertaken using spreadsheet and GIS softwares (Microsoft Excel and ESRI ArcView3/ArcGIS9). The measured metric data (distance, horizontal angle and vertical angle from a measurement point) were converted into global coordinates according to the base point coordinate in the UTM Zone-36N projection (X = 567748.46 m, Y = 4357336.74 m, Z = 1069.6 m). The point distribution was then obtained in the global coordinate system (Fig. 1A). During this conversion, errors found by the closed traverse of the measurement points were dispersed for each of the measurement points. The amounts of the error dispersion were –0.52 m for X, –1.18 m for Y and 0.00 m for Z.

In order to find points having anomalous Z-values, a Triangulated Irregular Network (TIN), which directly represents the surface connection of the points with triangular faces, was generated from the points. Points having Z-values anomalously larger or smaller than those of adjacent points are clearly shown in the TIN surface as spikes or wells, so that one can easily identify such error points. A contour map created from the TIN surface also helps to identify the error points. With the criterion of 2 meters for the Z-value, 16 points out of the 1,432 points were found and eliminated as anomalous points. Such anomalous Z-values may be derived from errors in the measurement operation, branches of tall bushes, and/or mismatch of coordinates for different measurement points. The remaining 1,416 points were used for the following processes of the land surface topography construction.

As a continuous surface of the landform, a DEM was then generated by interpolating the point data. The interpolation method applied here is the ordinary kriging method, which can appropriately generate a topographic surface from scattered points (Takahashi *et al*. 2003; Hayakawa *et al*. 2007). The grid cell size, *i.e.*, the resolution of the DEM, is set to be 2 m according to the point-to-point distances. After testing some semivariograms, the function type of the kriging interpolation was determined to be the exponential function, with a nugget effect of 0.5 m, range of 348 m and partial sill of 76.9 m. The nugget value, which is regarded as smoothing parameter, indicates that an approximate vertical accuracy of the point coordinate is as small as 0.5 m, which seems good enough as topography data. Contour lines with 50-cm interval were then generated from the DEM using GIS (Fig. 1B). The resultant DEM also gives various representation of the land surface topography, such as hillshade (Fig. 1C) and slope angle distribution (Fig. 1D).

COMBINED LANDFORM DATASET

Concatenating the point data above and those acquired in the 2005 season (Hayakawa and Kashima 2006), an extensive dataset of landforms around Kaman-Kalehöyük is obtained. After further removal of error points, the number of points used in the following analyses was 3,403 (Fig. 2A). Testing semivariograms, an ordinary Kriging interpolation was performed over the points, with the exponential function type, a nugget effect of 8 m, range of 393 m and partial sill of 52 m. The output grid cell size was set to be 3 m, in order to keep the high resolution of the original point distribution. The nugget value (8 m) is somewhat large in this case, suggesting that the vertical accuracy of the resultant DEM (Fig. 2B) is lower than in the DEM generated from the 2006 data (Fig. 1), due probably to the sparser point density in the dataset of the 2005 season. The layers of the DEM-derived contour lines (1-m interval) and the features of ground objects (obtained in the 2005 season) were then draped over the DEM image, giving an extensive topographic map of the area (Fig. 3).

DISCUSSION AND CONCLUSIONS

Connecting the LRF to the tablet PC substantially improved the time needed to acquire the landform data. In the 2005 season, the time period for the field measurement with manual data collection was 3 days for ca. 2,000 points (Hayakawa and Kashima 2006), whereas the time was only 3 hours for 1,432 points in this study. Furthermore, the post-processing time was also considerably shortened, because automated data collection does not require manual keyboard entry of the collected data list. Artificial error during manual data entry can also be avoided by the automated method. In addition, whereas two persons are recommended for efficient data collection by the manual method, the new method can be performed exclusively by one person.

The high-resolution topographic data shows that the outline of the tepe is polygonal rather than completely circular. According to the contour lines, the edge line and surrounding slopes of the tepe seem to comprise several linear portions (Figs. 1, 3). This may reflect the subsurface constructions of the tepe. Such topographic characteristics of the tepe are barely visible in existing topographic maps with lower resolutions.

The digital dataset of topography enables some GIS-based geomorphological analyses. Paths of surface water flow are obtained from the DEM using hydrological functions in GIS (Fig. 4). Although there seem to be some artificial characteristics in the flow paths (long linear ones) due to a limitation of interpolation especially in areas with scarce points, the water flow courses basically represent the actual streams running from south to north in the area. Fig. 4 shows that the top surface and surrounding slopes of the tepe have limited water concentration, indicating that the surfaces of the tepe are less irregular than the surrounding areas modified by fluvial, hydrological and geomorphic processes, and that the landform of the tepe is artificially organized. The parallel linear paths in the north side of the tepe are solely artifacts during the data processing, *i.e.*, due to the filling process of topographic depressions for the flow path acquisition. The topographic depressions in the vicinity of the tepe indicate that the area favors deposition rather than erosion.

Cross sections of the topography around the tepe can also be readily obtained (Fig. 5). The elevation of the top surface of the tepe is lower than that of the nearby hilltop (eastern side) by several meters, indicating that the tepe is not visible from the eastern areas over the hill. The bottom level on the western side of the tepe is lower than that on the eastern side (section ii), suggesting that the western side can be more favorable for water flow concentration. The descriptions above are based on the current landforms, and depth data of surface deposits may be necessary to reconstruct the ancient landforms in the area.

A three-dimensional view of landforms in the area is also readily obtained from the DEM. Fig. 6 shows a three-dimensional view of the contour lines, with an aerial photograph that was geometrically corrected using IDRISI GIS software. These data are suited to perform an overview presentation and preliminary investigations of the topography of Kaman-Kalehöyük.

The digital dataset is also suitable for being incorporated into a database that handles spatio-temporal information of archaeological properties (the AISDAS project, proposed by Tsumura and Suzuki [2005]). This database deals with various kinds of cultural and environmental properties, and a digital topographic dataset is one of the most basic pieces of information. Further data collection by this method will therefore contribute to the database construction, and will be the basis for broader applications of the AISDAS.

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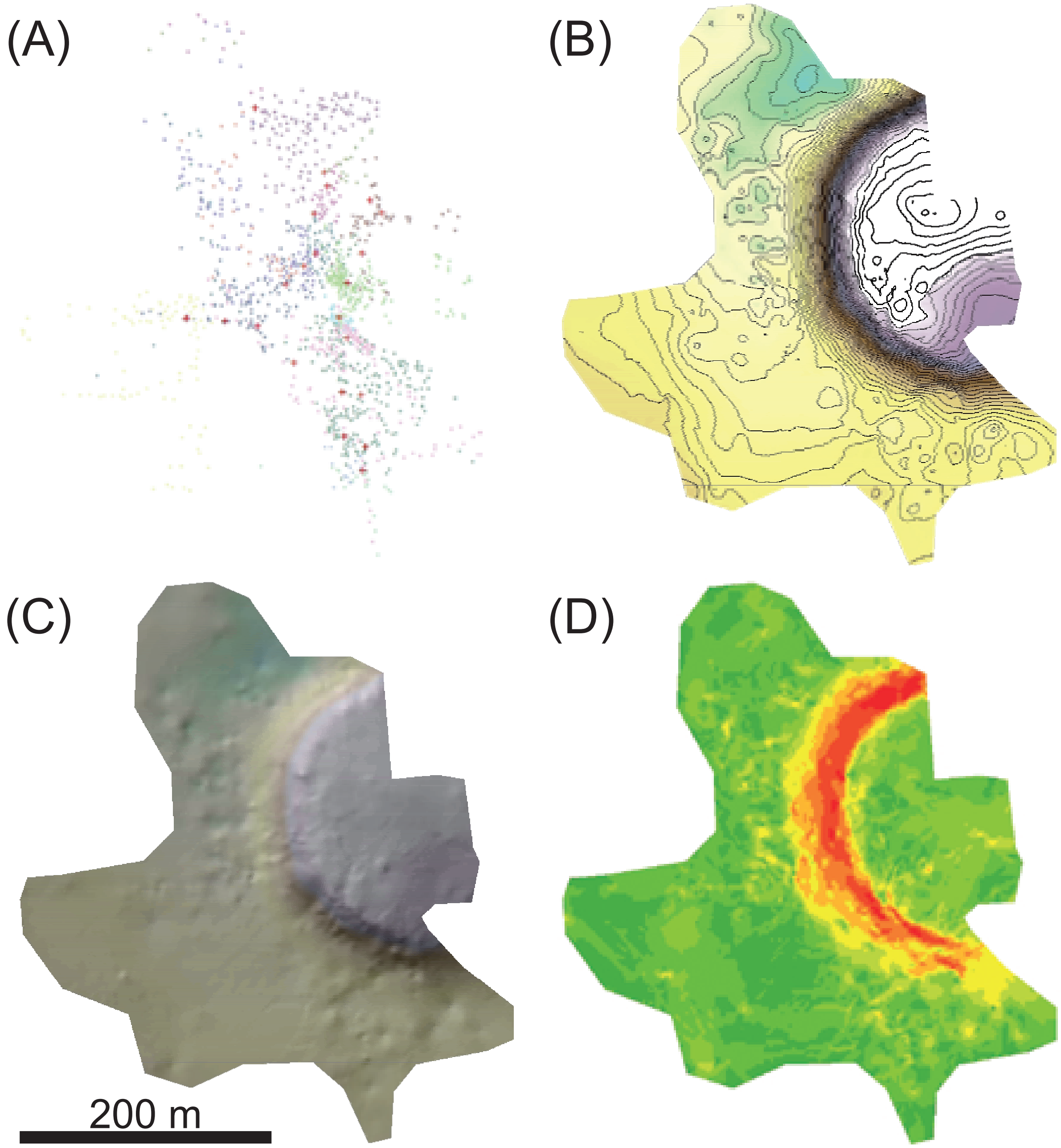

Fig. 1 Landform data of the southwestern area of Kaman-Kalehöyük obtained in 2006. (A) Distribution of ground surface points (colored circles) obtained from each of 21 measurement points (red crosses). (B) Contour lines with 50-cm intervals over a colored elevation grid interpolated from the data points in A. (C) Hillshade draped over the elevation grid. (D) Slope angle distribution. Red colors indicate steep slopes, while green colors indicate gentle lands.

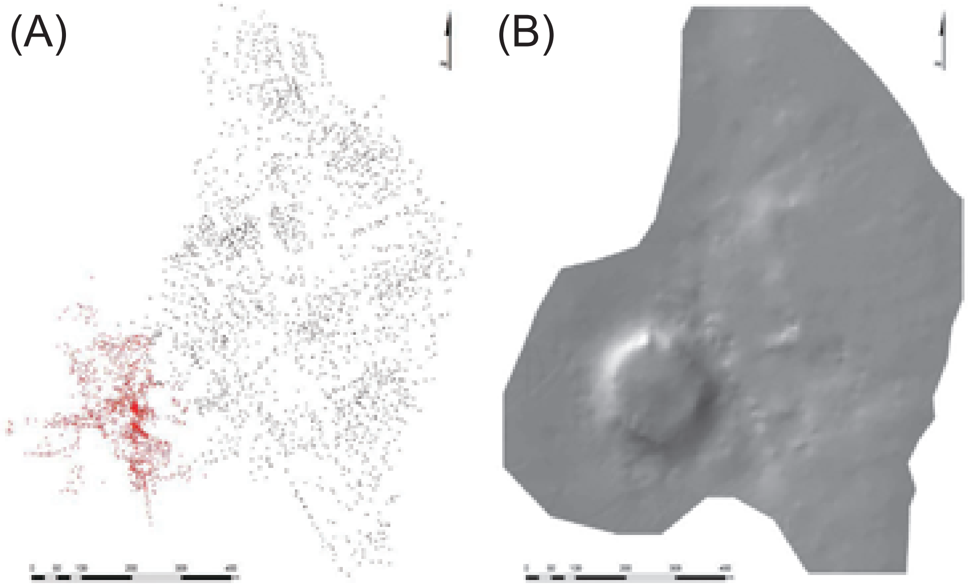

Fig. 2 Landform data around Kaman-Kalehöyük obtained in the 2005 and 2006 seasons. (A) Point distribution of the 2005 season (in gray) and 2006 season (red). (B) Hillshade image generated from the DEM after a kriging interpolation.

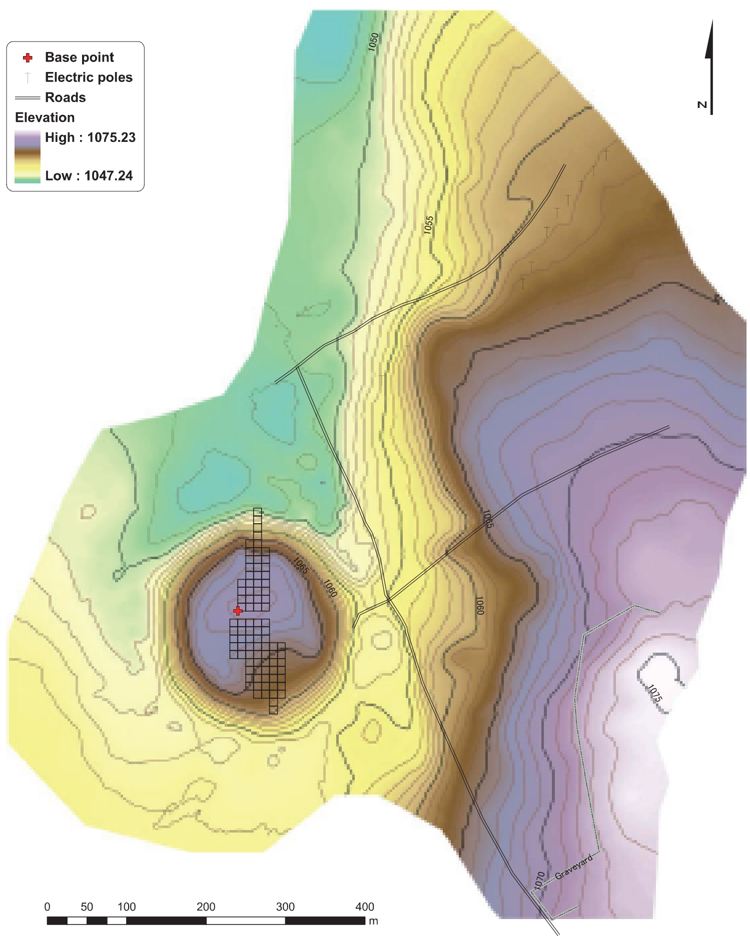

Fig. 3 Topographic map around Kaman-Kalehöyük based on the datasets of 2005 and 2006.

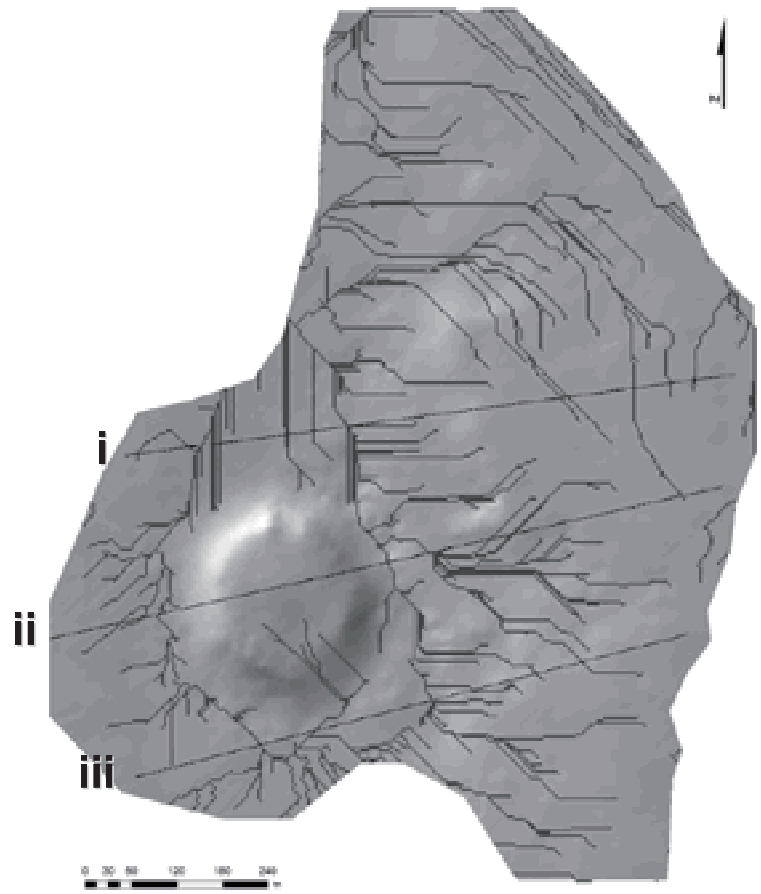

Fig. 4 Surface water flow paths derived from the DEM. Numbered lines (i–iii) indicates locations of cross sections in Fig. 5.

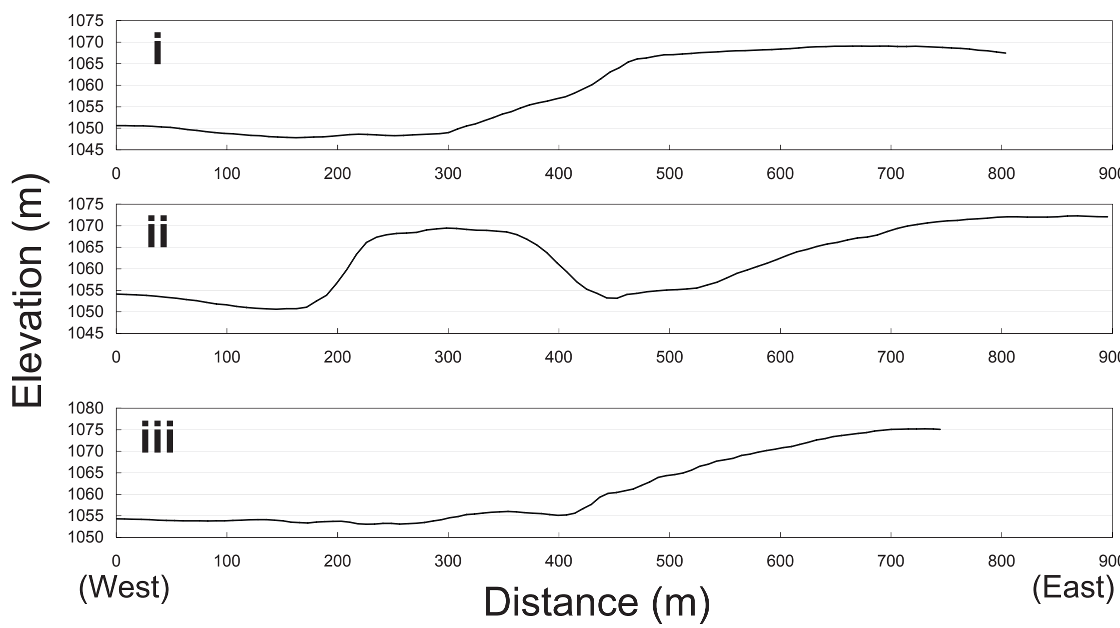

Fig. 5 Topographic cross sections around Kaman-Kalehöyük, looking from the south. See Fig. 4 for the locations.

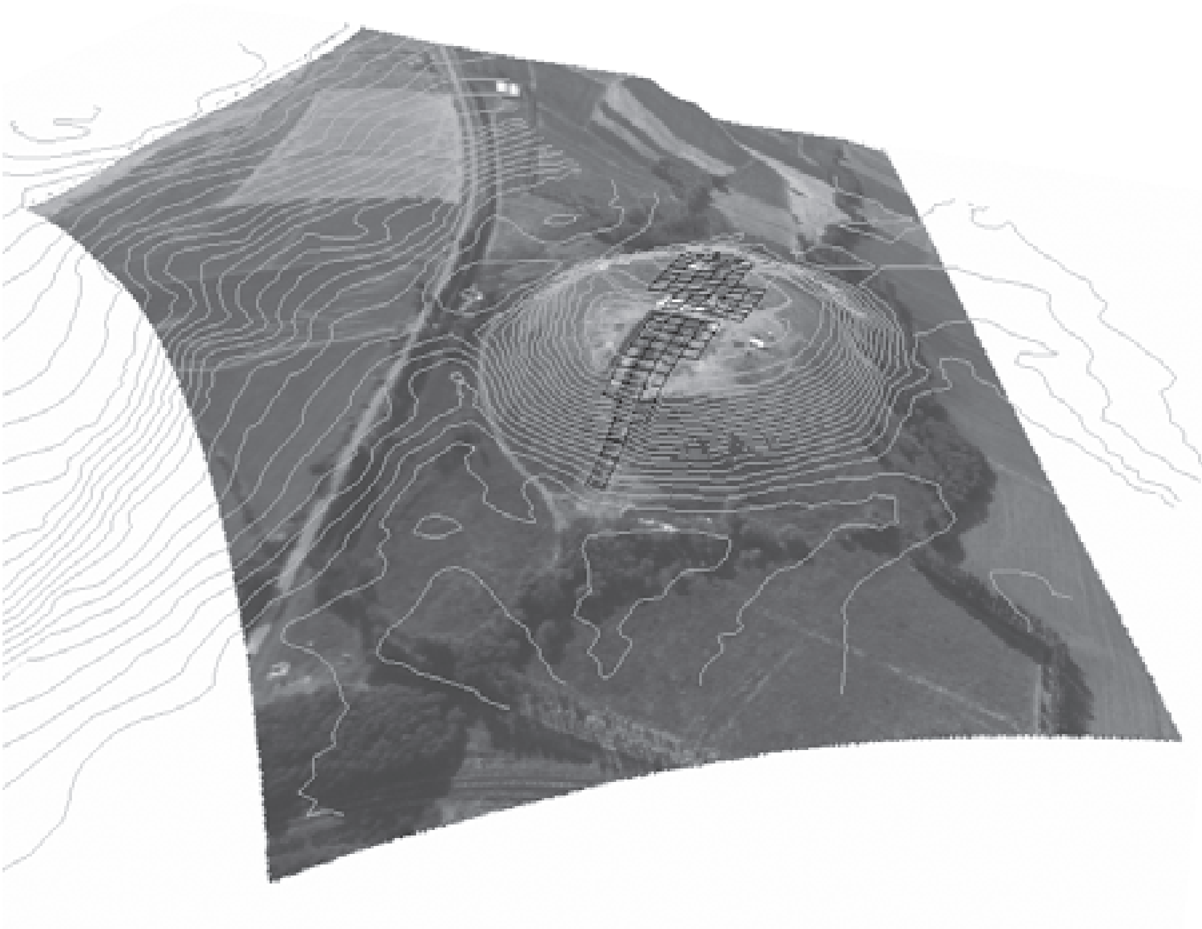

Fig. 6 Oblique view of Kaman-Kalehöyük with a geometrically-corrected aerial photograph.