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Falling into Place: Orientation and Viewing of Past Cityscapes in 3D Space

Keywords: historical photographs, historical maps, external orientation, georeferencing, cityscape, crowdsourcing, Google Earth.

Summary: Historical photographs of urban areas are a valuable source about the past, providing an interesting means of comparison with the present day situation. In order to make this comparison as direct as possible it is attempted here to "superimpose" the present and the past situation in 3D space; the proper procedure for performing this task is to calculate the exterior orientation of the historical photo in question. In our work we attempt to do this by means of correlating points on old photos with their counterparts on maps. It is very often the case that the information and data present on old photos cannot be traced on present day maps, so historical maps of the same period are necessary to provide correlating info. Therefore, old maps are georeferenced on modern ones, in order to provide additional information and consequently use the resulting coordinates for calculating the center of photographic projection *O* and its location and attitude in 3D space $(X,Y,Z,\omega,\varphi,\kappa)$. After this step, the photos can be properly placed on Google Earth.

Introduction

Historical photographs of urban areas constitute a valuable and rich source of information about the past and consequently provide an interesting means for comparing their content with the respective present day situation. In order to make this comparison as direct as possible a superimposition of the present and past situation in 3D space is attempted. The proper way to accomplish this requires the knowledge / calculation of the exterior orientation of the historical photos concerned.

In order to calculate the exterior orientation of any old photo one has to start by establishing homologous points on the photo and on a respective map. This is done in order to provide points, with both their photographic and map coordinates; from these pairs of coordinates of respective points the exterior orientation can consequently be calculated by means of photogrammetric procedures. The exterior orientation provides the center of projection *O* with its location (X,Y,Z) and attitude (ω,φ,κ) in 3D space.

The maps used for providing the coordinates of the abovementioned control points may occasionally be current ones (i.e. maps depicting the topography of nowadays), but most of the times the need for using older maps is inevitable, since the information on old photos might be difficult to correlate with the present day cartographic situation: often objects and points on old photos simply do not exist anymore and cannot be traced on a modern map. The information and data captured on historical photos, therefore, most of the times has to be correlated to respective historical maps of the same period. For this purpose old maps are georeferenced, in order to be transformed to the coordinate system of the present-day reference map(s) and combined with current geographic information. After calculating a photo's exterior orientation parameters mentioned above,

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the photo can be properly placed on Google Earth. In the following the procedure is given in more detail and test cases are shown.

Past cityscapes in current surroundings

Merging photos of the past into present day reality is undoubtedly attractive. Some examples of the concept are demonstrated below, concerning old photos and paintings of Budapest and London respectively.

Figure 1. Budapest old and new, by the Hungarian photographer Kerényi Zoltán (source: URL1).

Figure 2. Paintings of London past, as projected on Google Street View photos: *A View of Greenwich from the river* (1750-2) by Canaletto (left), *St Martins in the Fields* (1888) by William Logsdail (right) – source: URL2

Apart from the charm of such visual comparisons and temporal correlations, there is a potential for their use as valuable sources of information about the past, especially when combined with popular digital tools, such as Google Earth. The examples shown in Figures 1 & 2, for instance use a 2D projective transformation in order to position the old photo onto the two-dimensional plane of the current view. In our work we attempt to expand this 2D approach, by means of establishing the location of past cultural objects (such as old photos, paintings etc.) in true 3Dimensional space, with the help of the abovementioned photogrammetric procedure. Afterwards, the use of the widely known environment of Google Earth can provide a popular and easily accessible hub for storage of the results and for crowdsourcing relative information.

Photo Orientation Procedure

The core of the developed application consists of the photogrammetric procedure for the exterior orientation of photos. A prerequisite for this is the establishment of the cartographic basis of the area in concern, so that the ground coordinates of the control points necessary for the calculations can be collected. An outline of the procedure followed is given in Figure 3. During the preparation of the cartographic material often old maps will need to be georeferenced and combined with present day map layers, so that respective characteristic points can be located on the resulting "working map" as well as on the photo. These points (referred to as GCPs: ground control points) are used by the exterior orientation algorithm developed and presented in the following.

The exterior orientation of a photo can be described as the procedure determining the location of (the center of) the camera lens in space and the orientation of the camera's optical axis.

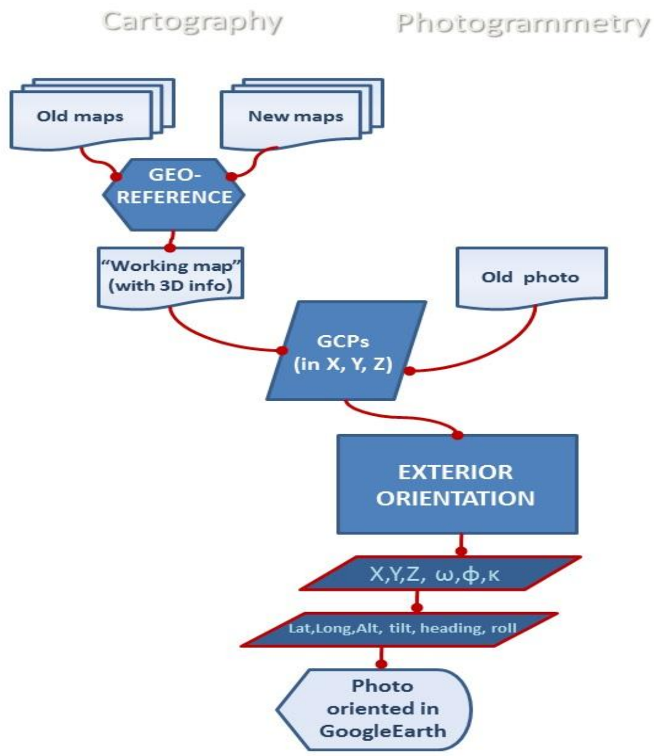

Figure 3. Flow diagram of the procedure followed for orientation and viewing of old photos in 3D space.

For the calculation of the above, i.e. the camera's position and orientation in 3D space, the software package "*ExteriorOrientation*" was used. The package was developed at the Aristotle University of Thessaloniki during the academic year 2013-14, for use in the educational procedure related to the course "*Introduction to Photogrammetry*", of the 4^{th} semester of the Rural and Surveying Engineers' curriculum of studies. Although initially educationally oriented, the software can be used for single-image resection, either from a digital camera output or from scanned documents (air photos as well as common terrestrial photos), provided that the respective interior orientation of the images has been determined (or the size of the cell of a digital sensor is defined, in μm), and that the focal length of the camera used is set to a known value. The advantage of the software is due to its ability of determining the exterior orientation without knowledge of approximate values (one of the most important problems in the least squares algorithm for resection calculation is exactly this i.e. the input by the user of suitable approximate values of the location X,Y,Z of the lens center and of the rotation angles ω,φ,κ of the photographic system axes).

Determining the elements involves a two-step procedure. The calculations performed in the first step concern the estimation of the position of the intersection of three spheres, the centers of which are the control points measured on the photographic image. As shown in Figure 3, the lens center can be defined as the intersection of three spheres, the radius of each is the distance of each control point from the optical center (i.e. the point in space from which the photo was shot). The distances (a, b, c) cannot be defined directly; nevertheless from triangles (ABP, ACP and ACP) it is possible to calculate the angles α,β,γ (via the well-known trigonometric cosine formulae) and consequently to compute the sides of the triangles starting from the photographic projection center and ending at the three control points. This is a specialized approach, based on the solution of a 4[th] degree equation. (Jancsó, 2004). Consequently, triplets of control points in all possible combinations are used, in order to determine the intersection of spheres and the estimated center of projection of the photographic image.

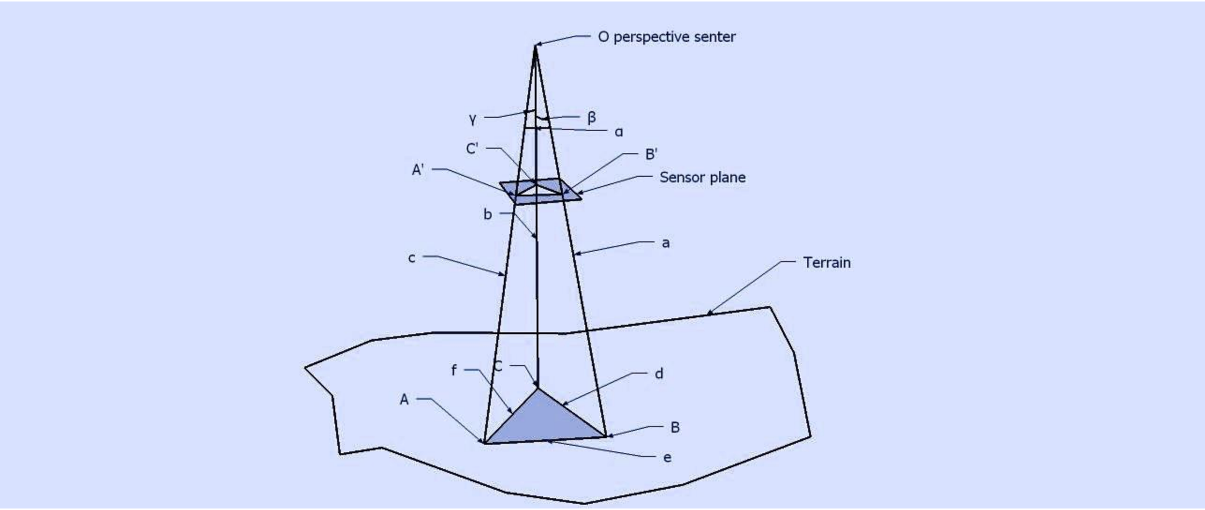

Figure 4. The geometry used by the resection algorithm (see text for explanation).

In the second step of the procedure an estimation of the most possible position is done, on the basis of the amount of closest solutions; the method of least squares adjustment in combination with the collinearity equation is used (classic photogrammetric resection) for the determination of the rotations ω,φ and κ of the photo shot.

Finally a couple of coordinate conversions in order to prepare for input in Google Earth are necessary (see Fig. 3). Some examples of the software's tests are shown in the following.

Photo Orientation Examples

The images used for testing the software are old photographs of the city of Thessaloniki, both aerial (oblique) and terrestrial.

Photo I: An aerial oblique photo of the city of Thessaloniki from the South.

In the first example (Fig. 5) an oblique aerial photo of the city of Thessaloniki, viewed from the South is used. The photo dates back to the period between the late 1950s and early 1960s and its interest lies also in the fact that it is an unusual point of view among the city's available popular depictions, showing an intermediate phase of the embankment of the natural shoreline south of the city, which took place in the period 1950-1973. For the photo in question, since there was no other information apart from the image itself, some assumptions were made, which led to a satisfactory solution.

Initially, an estimation of the film format was made, on the basis of the height to width ratio of the photographic image. The ratio (1200/864pixel) is approximately 1.38, a number very close to the ratio of the dimensions of a 135 film (ISO 1007) introduced by the KODAK company (and having dimensions 36x24mm). We assumed that only part of the horizontal extent of the photo was available and that the photo had been partially cropped, in order to fit to the digital document accessible to us. Given the vertical dimension of 24mm it was estimated that the digital image's resolution is approximately 27μm.

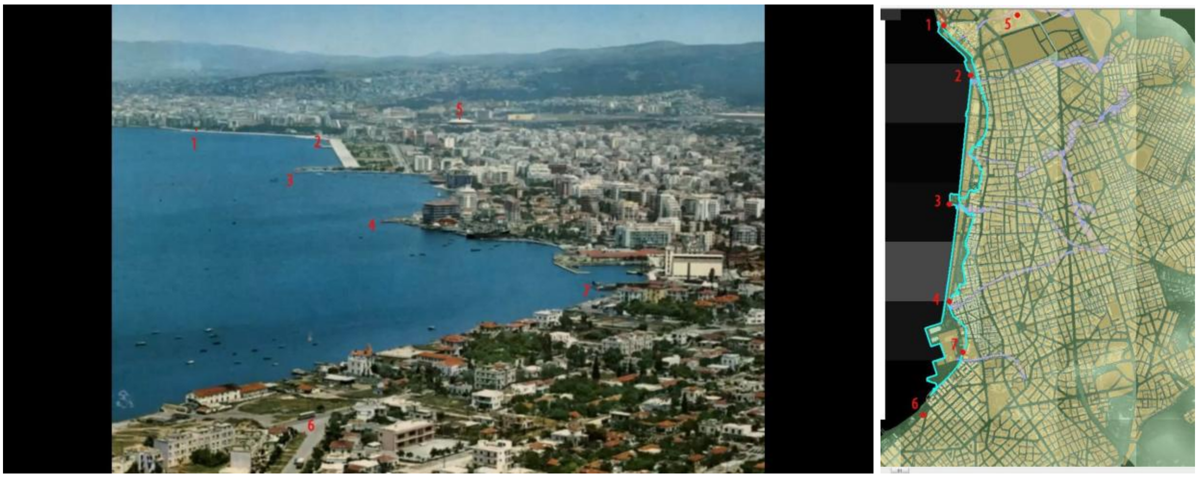

Figure 5. Left, the oblique aerial photo, used for the exterior orientation determination: it depicts the sea front of the city of Thessaloniki from the South, in the late 1950s-early 1960s (marked in red are the ground control points used); Right the same GCPs on the working map of the area: two states of the shoreline can be seen colored in cyan; the inner (older) one was traced from (georeferenced) old topographic maps of the city.

On the basis of this pixel size for the image, the interior orientation was performed. The last necessary item for the exterior orientation determination was an estimation of the camera's focal length. The most common cameras of that period used 50mm lenses, so a first attempt for performing the resection was done with the use of this value; however after analysis of the solution via the calculation of the residuals and their projection on the original photo (Fig. 6), the final best estimation, through an iterative procedure, resulted in a value of 108 mm.

Figure 6. The residuals of GCPs projected on Photo I after its exterior orientation.

Although the solution might seem not perfect, since the presence of residuals would not be acceptable in a classic photogrammetric resection case, it is significantly approximating reality (position and rotations) and the conditions of the photo shooting, given the fact that there is an information gap regarding the camera's focal length and the format of the image (film). This satisfactory outcome is evidenced by the well-matching positioning of the photo image in Google Earth, by feeding the resulting values of the position (φ,λ, altitude) as well as the rotation angles (heading, tilt and roll) to the available Google Earth interface.

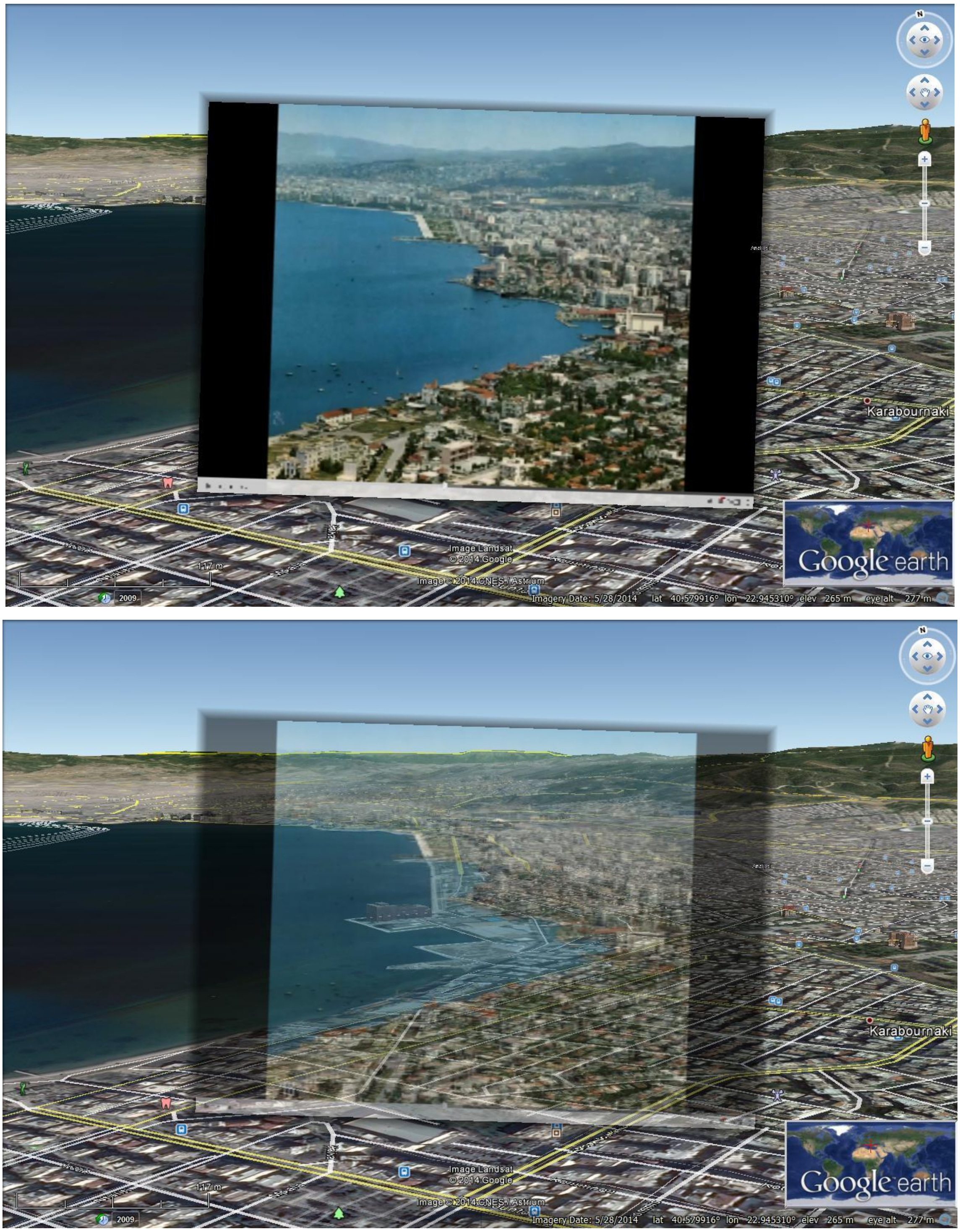

Figure 7. Photo **I** positioned in Google Earth, according to the values of the exterior orientation parameters; the possibility to modify the old photo's transparency enhances visual correlation.

***Photo II: A terrestrial photo in the center of Thessaloniki city*.**

Another example for the implementation and testing of the software was carried out using a terrestrial photo from the early 20th century depicting *Diagonios*, a location in the center of Thessaloniki (Fig. 8)

Figure 8. The spot of *Diagonios* in Thessaloniki, early 20th century.

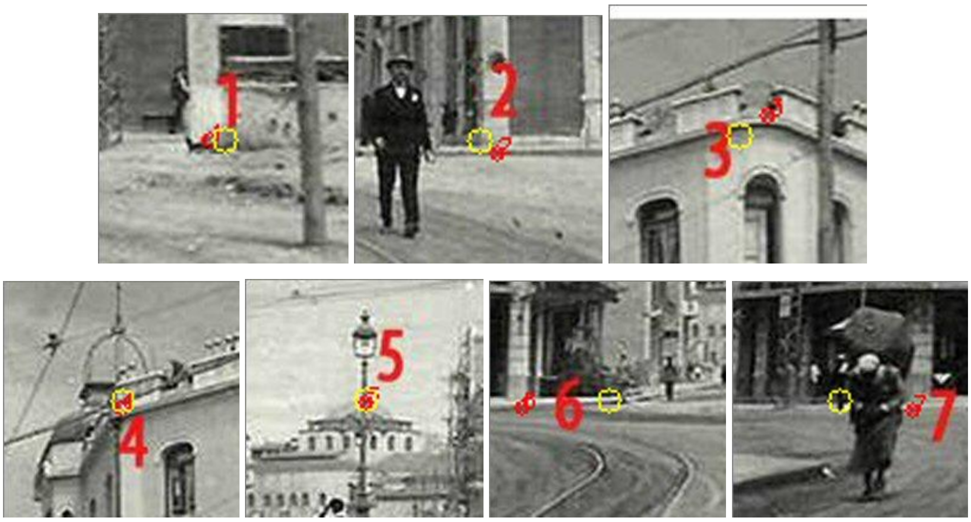

Figure 9. Photo II, residuals of GCPs after the exterior orientation.

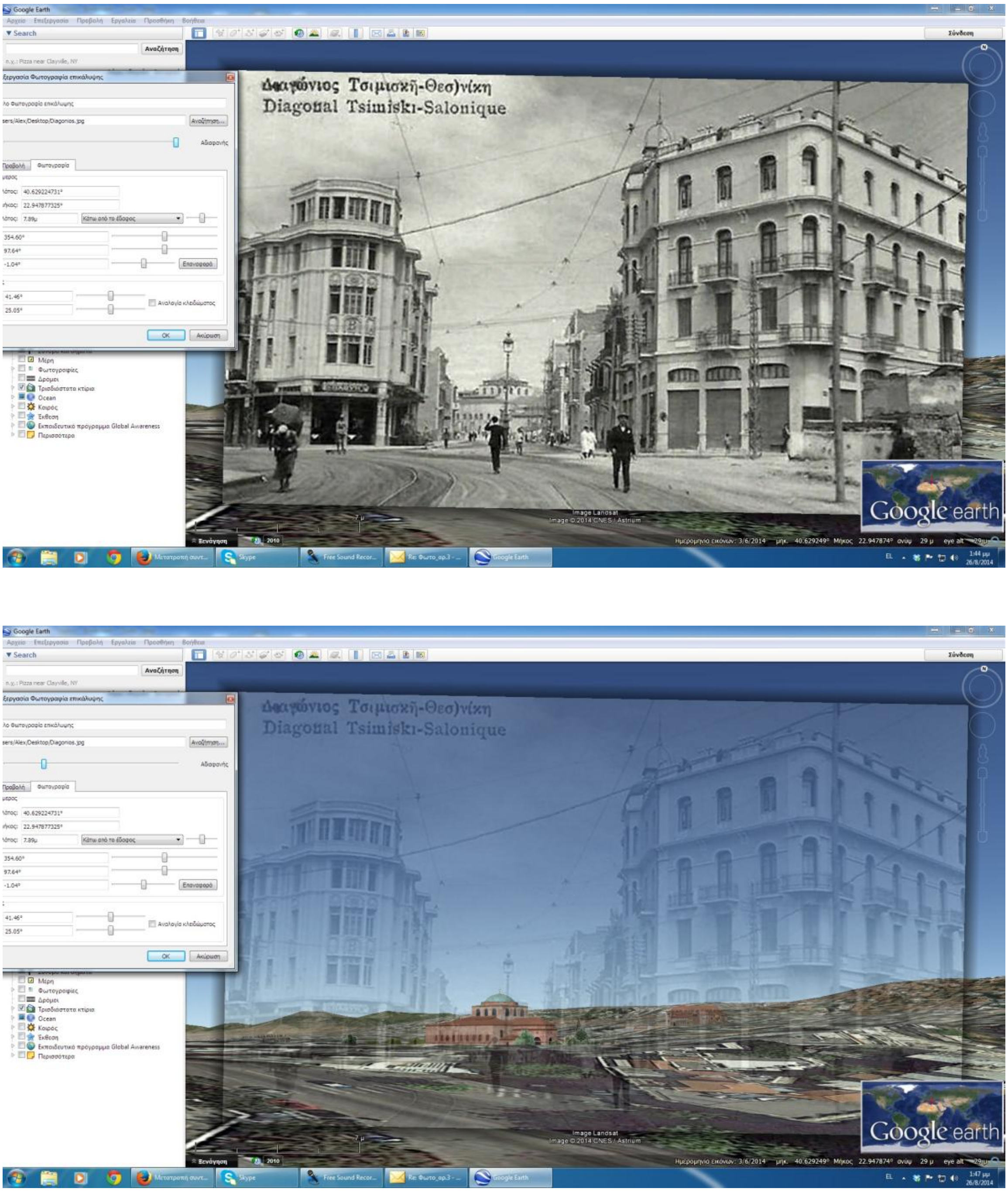

Figure 10. Two snapshots of different transparency of Photo II positioned in Google Earth, according to the values of the exterior orientation parameters.

Working similarly, we used here a focal length of 50mm and a pixel value of 0.05mm. The resulting residuals are shown in Figure 9 and the estimated position of the photo is used for placing it in Google Earth, according to the exterior orientation parameters (Fig. 10). By manipulating the transparency one can compare to the present day topography. The more 3D features are available on Google Earth, the more interesting the visual comparisons. For instance here the monumental church of Hagia Sophia (6th century) is visible in both the old photo and on Google Earth.

Photo III: An "extramural" view of the city of Thessaloniki from 1910.

The panoramic view of Thessaloniki shown in a photo from 1910 (Fig. 11) was used for another test. The photo is taken from a spot outside the city walls, a location from where the city started to expand southeastwards, from the late 19th century and onwards; 150 years ago the place was uninhabited, occupied by rural areas, barracks, cemeteries and torrents; in the photo below the first transitions to urban use are witnessed. Nowadays the area is completely transformed to a busy urban environment (Fig. 12).

Figure 11: A panoramic view of Thessaloniki, outside and to the south of the city walls (1910).

Figure 12: The area of Photo III as depicted today in Google Street View.

In this case, an attempt to locate matching points required the use of old maps, since most of the old photo's items do not exist anymore and consequently no current map is adequate for gathering a satisfactory number of control points, necessary for performing the exterior orientation procedure. For this reason we acquired a number of map sheets, dating back to the end of 19th – beginning of 20th century. These were made available in digital form by the Hellenic *Archive of Cartographic Heritage* (former *National Center of Maps and Cartographic Heritage – National Map Library*) based in Thessaloniki, which is responsible for the digitization, managing and availability of these and other similar cartographic documents. The map sheets' physical collection belongs to the Thessaloniki Municipal archive of urban maps (see e.g. Livieratos, 2005).

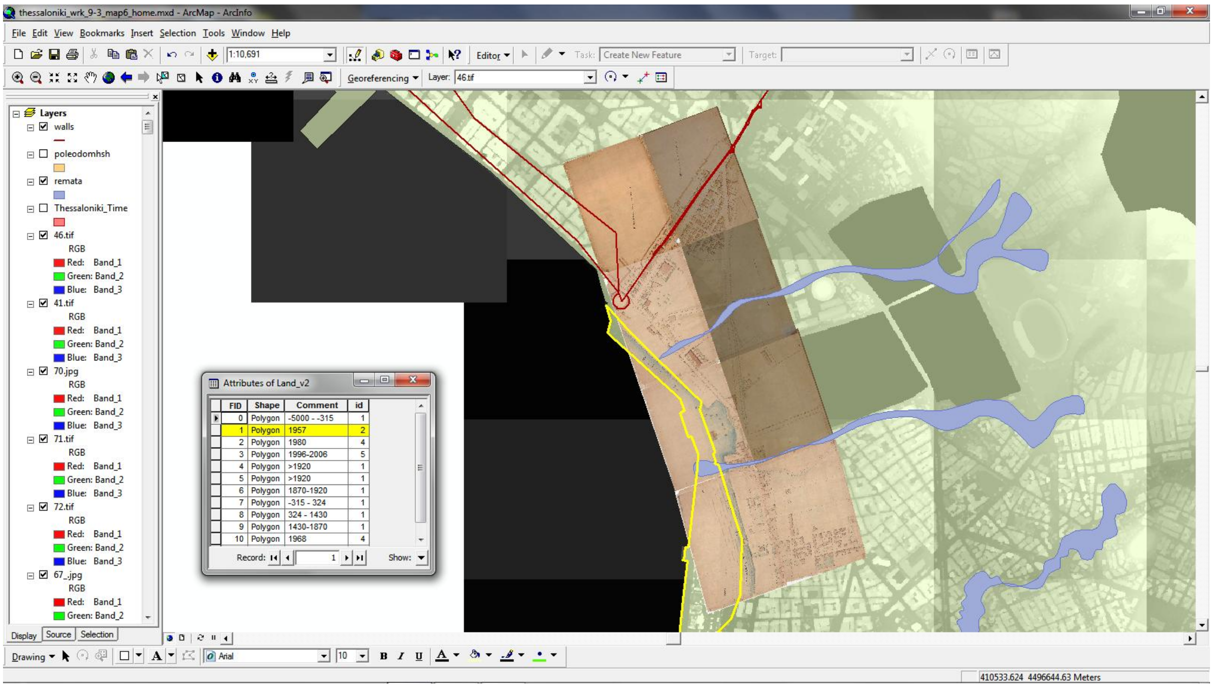

Figure 13. In the "working map" environment a number of historical map sheets, contemporary to the old photograph in question were georeferenced for providing points matching to the photo's details. A digital surface model (underlying the map sheets) was also used for providing height information necessary for the resection calculations.

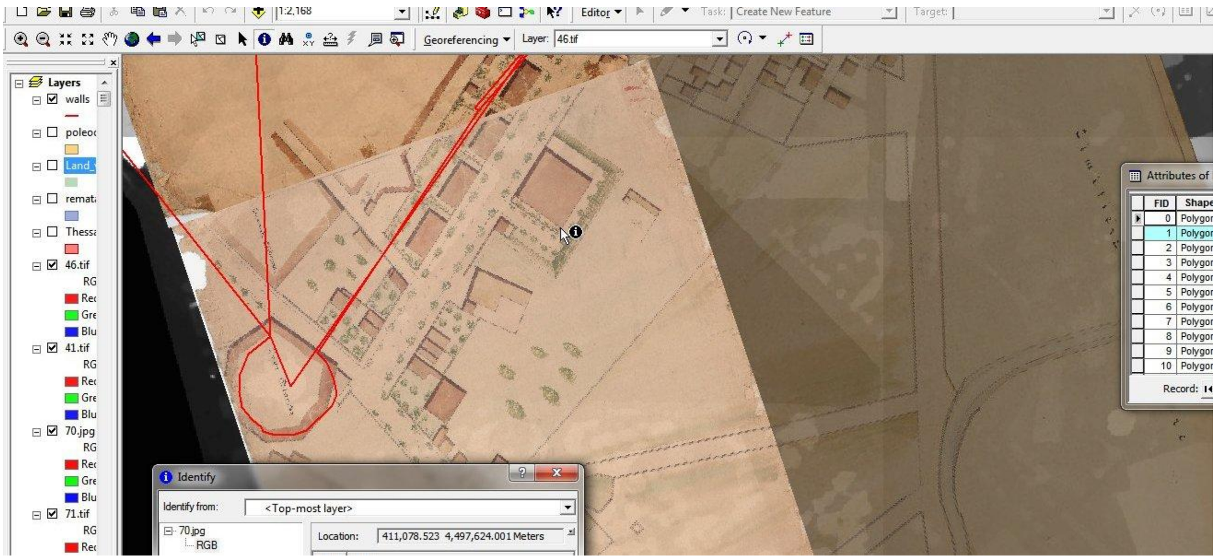

Figure 14. Locating points of detail on the old map sheets and obtaining map coordinates.

The panoramic photo is actually a compilation of a sequence of photos, which have to be oriented separately. The results concerning the middle part of the photo are shown in the following Figures (Fig.15-17). The focal length used in this case was 150mm.

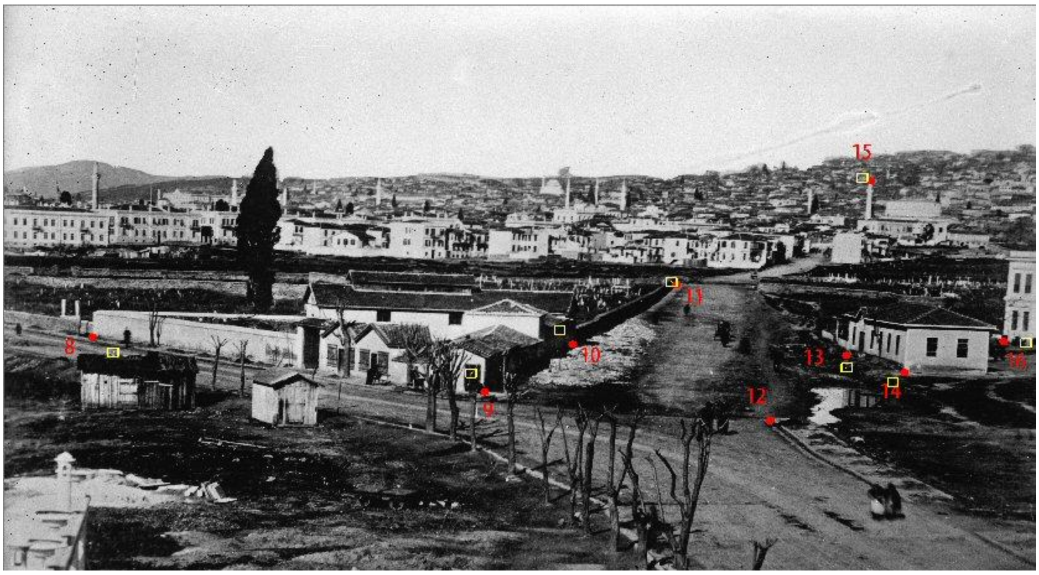

Figure 15. The residuals of GCPs for Photo III (middle part).

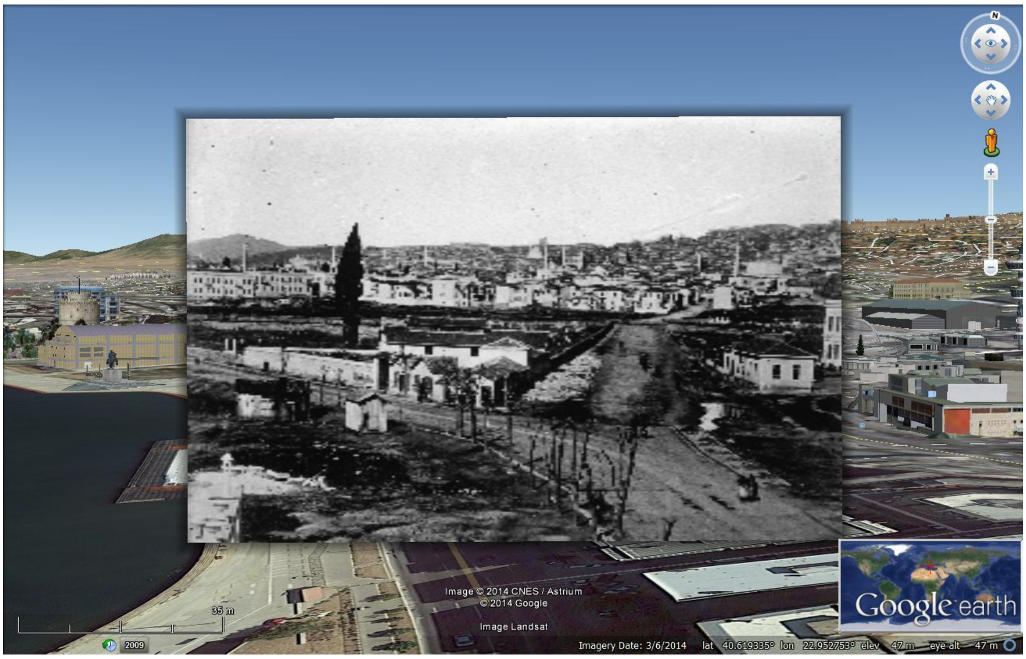

Figure 16. Middle part of Photo III fallen into place.

A few remarks and conclusions

As previously mentioned, the software package used here, although developed for limited use, gave quite satisfactory results in the exterior orientation test performed to photos with different characteristics and at the same time pointed out the need for some possible improvements.

For the purposes of the work we used photographs that were publicly available, mainly in books and on the web; most of the times these were not of the best quality. If original /good quality copies are available this will contribute to the quality of the results, since points will be estimated better on the photo.

In a broader context, the combination of photogrammetric and cartographic interests and techniques for the purposes of processing items of cultural and historic importance offers interesting possibilities for developing tools that might be of use in relative studies.

Figure 17. Modifying viewing parameters of the oriented photo, in Google Earth.

Acknowledgements

The authors appreciate provision of the digital copies of the 1898-99 map sheets and user permission, made possible by the Hellenic *Archive of Cartographic Heritage* and the Thessaloniki Municipal archive of urban maps, respectively.

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URL1: http://ablakamultra.hu/

URL2: http://imgur.com/a/jdIM0