Study of Erbil Al-Qala citadel time changes by comparison of historical and contemporary image data

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ABSTRACT
The Erbil Al-Qala citadel is located on a distinct hill (“tell”) in the foothills north of Iraq, in Kurdistan. The citadel is a historical city centre of presently rapidly growing Erbil, which is the capital city of the autonomous region of Kurdistan. The citadel has been inscribed on the World Heritage List since 21 June 2014. The Erbil citadel dates back thousands of years to the first settlers of Erbil. The resulting shape is a large, oval hill, and is properly referred to as a “tell”, which means a large mound created by many generation buildings one on top of another. There are historical aerial photographs of Erbil citadel made by Bradford in 1951. These unique images are taken as a stereoscopic image pair configuration. A digital model and historical orthophoto has been created from this data set. A basic map of the citadel has been created based on modern VHR satellite data and field measurements. Bradford’s historical images were processed in Agisoft PhotoScan software. Satellite images taken by Ikonos (2003), QuickBird (2005) and Pleiades (2014) satellites represent the second data sets. The created orthophotos and digital models of the citadel were mutually compared. The result is a map of missing objects that were destroyed during the second half of the twentieth century. Results based on image data processing from a long-term project of the CTU in Prague dealing with Kurdish historical monuments represent the main content of the proposed article.

Introduction
There are a large number of valuable historical monuments in Iraq and the vast majority of them are in a much-neglected state. This creates an urgent need to keep them for the future. The most common causes of damage to the monuments are wars and irregular maintenance. In 2006, two Czech expeditions were sent to Erbil for the preparation of basic documentation of monuments, archaeological research and finding a suitable technology for the renewal/restoration/reconstruction of these monuments. The first step was to acquire a photogrammetric and geodetic survey of the Al-Qala Citadel and the Choli Minaret in Erbil. The Erbil Citadel is recorded in the UNESCO’s list and forms an extensive complex of buildings and narrow aisles bordered by city walls. According to the ICOMOS council data, it represents the longest inhabited city in the world, about 8000 years. There are water resources that have never been dried or exhausted up to the present (Chini et al., 2015).

The citadel spreads over more than 10 ha of land with a diameter of about 350 m. It is the abovementioned hillock, where height of the peak is about 30 m above the flat surroundings. No maps or plans of the citadel were preserved, only copies of a cadastral map from the twenties of the twentieth century. Being a symbol of the Kurdish people, the structures were heavily damaged during the reign of Saddam Hussein. The main part was destroyed and subsequently a new modern portal was built in retro style in the 1980s. Further reconstructions were made in 1982, when seven houses were preserved. There was a new rehabilitation programme of the Citadel established around 2007 organised by HCECR. Since 2006, approximately 25 houses have been preserved, some of them under auspices of UNESCO. Currently, the citadel requires an extensive reconstruction demanding a great amount of wherewithal, a time-consuming and costly action to repair and survey the real state (Ur, Jong, Giraud, Osborne, & MacGinnis, 2013).

History of Erbil
The capital of the Kurdish Autonomous Region in northern Iraq is the UNESCO-listed town of Erbil. It is the longest settled place in the world. In ancient times, it was called Urbilum, Arba ilu or Arbela. In its time, it was the royal city of the Assyrian Empire, and its central position remained in the local region even to a younger era. The Citadel of Erbil is situated at a 25–32 m high tell, where remains of settlements up to
seven millennia back can be found. It is the most significant monument of Northern Mesopotamia and at the same time forms a natural urban centre. The earliest written reports of the town date back to the time of King Shulgi ca. 2095 to 2048 BC. The greatest prosperity the town achieved was during the reign of the last Assyrian kings in the eighth and seventh century BC. It is related to the goddess Ishtar of Arbelia, to which a temple was built. This temple, along with its oracle, astronomical observatory and royal palace, has left its remains in the tell’s body up to the present. Erbil served as the centre of the province even after the dissolution of Assyria and at that time became a heart of spreading Christianity in the Tigris river basin. Once the Muslims conquered the city in 642, its glory and bloom declined. The revival took place in the twelfth to thirteenth centuries, when the fortress was rebuilt and the lower town was developing. Since 1534, the city was under the Ottoman Empire. Today, the citadel consists of an irregular dense network of temporary buildings whose origin probably does not extend beyond the nineteenth century. The Erbil town itself, surrounding the citadel, has been reaching a very rapid increase in population since the end of the World War II. While at the end of the 1940s, around 40,000 people lived in the city; today’s population is considerably greater than 1 million and is still growing (Nováček et al., 2008; Abid, 2004; Pavelka, Matoušková, 2015).

The Erbil’s tell remained apart of archaeological interest because of its living area. Only random findings were performed during construction works in the second half of the twentieth century. A planned reconstruction of the damaged memorial complex would also bring its archaeological evaluation and documentation, which would serve to propose an appropriate archaeological research (Ur et al., 2013; Lawler, 2014).

There was an effort to obtain basic documentation and general data on the development of archaeology of the whole tell and the citadel. Methods were chosen to acquire a new survey of the site and to archaeologically research it using non-destructive methods such as geophysical research, surface collecting etc. This historical research has been pursued by the Czech professional public since 2006 as a part of an international project to help Iraq in the reconstruction of its cultural heritage. Prof. Pavelka has dealt with the geodesic and photogrammetric survey of historical monuments, whereas Dr. Nováček dealt with historical and archaeological aspects of the issues (Abid, 2004).

The geodetic measuring of the citadel was complemented by geophysical research. This has brought interesting results. In several places, large inhomogeneities at depths of 9–21 m were indicated in the northern half of the site, which should correspond up to 5-m stone blocks. These layers are probably remains of an extinct monumental architecture from the New-Assyrian period. Research opportunities are very limited due to the large housing density. Certain guides can also be found in written sources. In those from the Islamic period, it is noted that the exquisitely fortified administrative core of the town represented a part of an adjacent, separately fortified, city in a plain.

The documentation of the construction was gathered in a short time. Both terrestrial and aerial photogrammetry were used on site. In the case of the Citadel, sets of ground images were taken – about 250 outdoors and 200 inside. After many negotiations, approximately 80 pictures were taken from a US Army helicopter (taken by K. Pavelka) at an altitude of about 100 m. There is no modern or up-to-date aerial imagery available in Iraq (it is still non-flying zone and in 2006 was not possible to obtain any aerial or drone photographs – from military, technical and statutory reasons), so they were replaced with QuickBird satellite data of 65-cm resolution (Nováček, 2008; Ponižilová, 2011).

Available images

Bradford 1951

This stereo pair was probably taken in 1951. The authors’ photogrammetric laboratory obtained just scans of these images with no information about the camera and lens used as well as lens distortion. These images (see Figure 1) were processed in Agisoft PhotoScan. Five GCPs (ground control points) were used in processing and model georeferencing. All project GCPs were measured during geodetic campaign in 2006 using total station Zeiss-Trimble Geodimeter 1500 in local geodetic network. Primarily, GCPs were used for processing approximately 90 original aerial photographs taken from the US helicopter around the Citadel. After network adjustment, precision (mean square error) of GCPs varies from 1.5 to 3.8 cm in position; the largest length in triangular network is approximately 150 m; 16 GCPs were measured in total. All the GCPs were regularly deployed on the citadel’s territory and were marked by a steel nail and highlighted by a yellow-coloured photogrammetric target. Only a few GCPs were identified in historical aerial photos (as written above, only five) (Pavelka, Svatušková, Králová, 2007). But two of them evinced a 6-m height mean error. Orthophoto (Figure 2) and DSM (digital surface model) were created in UTM coordinate system using WGS84 ellipsoid. GSD (ground sampling distance) of the images is approximately 17.5 cm.
Quickbird 2005

This satellite image was taken in 2005 with GSD of approximately 0.65 m. Original image quality was not suitable for vector processing. For this reason, after many experiments, data and edge enhancements and filtering, resolution (GSD) of the data set was improved and resampled to GSD of 0.2 m. The aim was to improve quality for next processing because some features were hardly detectable in the original resolution. The state before and after the improvement is shown in Figure 3.

Pleiades 2017

Pleiades image stereo pair was taken in 2017 with GSD of approximately 0.5 m. Orthophoto and DSM were created from the stereo pair of images. The GSD of orthophoto is 0.5 m and of DSM is 1 m. Orthophoto of the Erbil Citadel is shown in Figure 4.

Transformations and georeferencing

Comparing implicit georeferencing of QuickBird 2005 and Pleiades 2017, a roughly 20-m shift in a northern direction was achieved. Moreover, there is a
skew of Pleiades images good visible as shown in Figure 8. When georeferencing, there was a necessity to deal with these difficulties. The QuickBird 2005 image was used for georeferencing of Pleiades 2017 image as a base georeferenced image.

**Quickbird 2005**

In this imagery, there were 16 GCPs terrestrially measured by total station (centimetre accuracy as described above) in the area of the Erbil Citadel in 2006. A local coordinate system was used for the measurement. Some of these points were measured by GPS with metre accuracy (code measurement) in 2007 for transformation from local to geodetic system. The terrestrial measurement was transformed using three control points only (which shown the best results of transformation, using similarity transformation) measured by GNSS to the UTM coordinate system. This transformation has preserved the intrinsic accuracy of the terrestrial measurement. Finally, the improved QuickBird image was transformed using 16 GCPs by collinear transformation to a photo plan which substitutes an orthophoto well enough in the small area of the citadel (orthophoto could not be created because of using single satellite image, not stereo pair).

**Bradford 1951 – orthophoto**

For georeferencing, Bradford’s orthophoto the QuickBird image was used. Better georeferencing was done because of high errors achieved on GCPs when processing in Agisoft PhotoScan. Another reason for georeferencing was residual shift of images. Sixteen well-identifiable (but not directly measured by geodetic technology) points were found in both QuickBird and Bradford orthophoto images (only a few GCPs measured geodetically in 2006 were found on Bradford’s photograph). The placement of control points is shown in Figure 5. Zero-order polynomial (ZOP) transformation was used with RMS equal to 2.1 m.

**Quickbird 2005**

A spline transformation was applied to the QuickBird image and Bradford orthophoto to 56 points to eliminate errors in the georeferencing. These control points were well-identifiable points in both images. It was found that images taken by linear sensor have lower intrinsic accuracy. In the case of the ZOP transformation used, the RMS would equal 1.7 m. Figure 6 shows control points used for transformation. This georeference was done because of removing residual shift of images and to remove points (edges, corners of buildings etc.) displacements of images.

**Pleiades 2017**

To eliminate the 20-m shift and the skew of roofs, the spline transformation with 67 control points found in the georeferenced QuickBird image was used. The QuickBird image was chosen because of better agreement of QuickBird and Pleiades images (higher temporal closeness of the images). In the case of the ZOP transformation used, the RMS would equal 3.9 m. Figure 7 shows placement of control points used for transformation. Figure 8 shows the correction of roof skew after using spline transformation. Note the blue roofs in the centre of the image. As you can see, these blue roofs at the top of Figure 8 don’t have perpendicular corners before using a spline transformation.

**Bradford central image**

For this paper, we call Bradford Central Image an image which captures an Erbil Citadel in the centre of the image. For transformation of the Bradford central image, a second-order polynomial transformation to
37 identical points on the Bradford orthophoto was used, where RMS equal to 0.7 m was achieved. The second-order polynomial transformation was chosen to correct the uncertainty of elements of interior orientation. Placement of identical points used for transformation is shown in Figure 9.

Data processing and results

The Bradford image was vectorised using ArcGIS in 2017. A resulting vector map can be seen in Figure 10.

Originally, the QuickBird image was vectorised in 2007 by Prof. Pavelka using Czech made software Topol. In 2007, shortly after the war against Saddam Husain regime, there was no possibility of better satellite images, and stereo-images could not be obtained simply and quickly in that time; for this reason, an orthophoto cannot be processed. However, because the upper part of the Citadel with houses and palaces is relatively flat and 16 GCPs were measured there, after transformation and image cutting (only the Citadel was the main aim in the satellite image), the result is similar to an orthophoto and can be used to feature vectorising. The vectorising of improved raster satellite image was made by hand using mouse; five layers have been created (vector buildings, electricity and pipelines, control points, object points from Photomodeler software, terrestrial images positions). Captured aerial photographs from the US helicopter were processed in Photomodeler to a 3D model of outer peripheral parts; a vector map was created for the inner parts from improved QuickBird satellite image with the help of terrestrial images taken from hand (approximately 2000 images). The vector drawing was transferred into ArcGIS as shown in Figure 11.

During vectorisation, two classes were distinguished – buildings and roads. After vectorisation, a differential vector model was created. Subsequently, some objects which were obviously changed were manually added to the layer of changes. The final differential vector model is shown in Figure 12. Unchanged areas are the areas with the same meaning in both years, e.g. if there was road in a particular place and it still exists there, it is considered an unchanged area and the same rule is used for buildings. Changed areas correspond to places built-up in the past and with no structures in the present or used as road in the past, with a standing building at present.

Table 1 shows changes in square metres and in percent. It is apparent that changed areas represent roughly 23% (which corresponds to 25,000 m$^2$) from the total area a little less than 108,000 m$^2$.

Conclusion

Unfortunately, the processing of the Erbil Citadel could not be performed completely. It does not include all changes because there are objects that could not be accurately detected – especially buildings on the edge of the citadel, but also in the middle of building blocks. In the satellite imagery, it is often difficult to determine whether a pair of structures in two images is about the same building or not. Changes are therefore much greater than indicated by the methods used. In order to determine better overall changes of the site over the reference period, it would be necessary to take pictures...
with greatly better resolution, such as using RPAS. However, all non-land measurements in a given location are problematic with regard to local conditions.

The Pleiades orthophoto was not used to create vector drawings, especially for its low internal accuracy as was shown in Figure 8. It was necessary to eliminate a skew of roofs as showed in the top of Figure 8. Quality true orthophoto, which seems to be the best for vectorising of features, could not be computed with adequate resolution because of image quality and skew of images. Apart from certain problems with the Citadel (location on the tell, very densely built-up areas with low buildings and narrow streets), this is generally a very small area from satellite point of view. Since the Citadel is displayed considerably skewed in the Pleiades data, there was rather used the QuickBird data which was taken almost vertically, which proved to be crucial.

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