The use of high resolution digital surface models for change detection and viewshed analysis in the urban area around the pyramids of Giza, Egypt

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Abstract— **One of the biggest threats to cultural heritage is related to their rapidly changing and developing surroundings. The Giza pyramid plateau is a prime example of this phenomenon, as it is threatened by the enormous urban expansion of Cairo over the last decades. Documenting, monitoring and modelling such a pressure requires accurate and detailed geographic data, which can be derived from recent up-to-date, high resolution satellite images. Remote sensing techniques have proven to be very useful to visualize and analyze urban sprawl and land use changes in two dimensions. The impact assessment of urban sprawl near specific heritage sites, however; needs to be complemented with accurate 2.5D-information. In an attempt to do so, digital surface models (DSMs) from Ikonos-2 (2005) and GeoEye-1 stereoscopic images (2009 and 2011) have been computed in order to analyze recent urban changes. Change detection methods are mainly developed for large scale high resolution aerial images; however this paper focuses on the one hand DSM creation and its challenges resulting in an improvement of 2.5D change detection method for small scale satellite imagery in mainly informal areas. On the other hand a view shed evolution is presented.**

The combination of the enhanced digital terrain extraction (eATE) module of Erdas Imagine® and ground control points collected in the field provides accurate and high resolution DSMs. The impact of shadow and different urban morphologies however influence the pixel-wise comparison of the two DSMs, which results in different approaches for different city districts. The resulting 2.5D change model clarifies not only the urban sprawl, but also the increase in building levels, directly related to pressure on the famous pyramids. This pressure is furthermore analyzed by creating different view sheds through time from the plateau towards the city and vice versa. An integration of population statistics complements the model, hence allowing it to become a useful policy instrument.

I. Introduction

Not only the increasing population but also the continually growing number of informal settlements provide a significant threat to the Giza Pyramid Plateau in Cairo(Shetawy and El Khateeb, 2009). The overall policy and failing master plans, resulting in satellite cities like 6th of October and Sheikh Zayed, have to a large extent impacted on the famous heritage site (Sims, 2010).These city changes can be quantified and analyzed using geographic techniques. Remote sensing has proven to be a very useful took for analyzing rapidly changing urban environments in developing countries. However this is mainly done in two dimensions (Yin et al., 2005; de Noronha Vaz et al., 2011; Taubenböck et al., 2012). Due to political and environmental restrictions buildings are also increasing in building levels (Sims, 2010). These changes cannot be detected using conventional 2D change detection techniques. DSMs provide the required 2.5D information to detect these urban changes. The combination of a high spatial resolution, up to 0.5m and large coverage makes recently launched satellites like Worldview and GeoEye a perfect source for creating very detailed, accurate and up to date DSMs. In this study, high resolution stereoscopic images from 2005, 2009 and 2011 providing information on the recent evolution and the current urban situation on the Giza Plateau have been used.

In this paper first the process of creating DSMs is explained followed by the pixel wise comparison resulting in a 2.5D automated change detection method in which different approaches are used because of different city morphologies. Most of these change detection methods were developed for large scale aerial images or lidar data with higher resolution. This paper evaluates if such techniques can be used with small scale satellite data in a high populated, dense city environment like Cairo and its surroundings. In a second step a viewshed analysis provides an idea about the evolution of visual impact on the heritage site.

Section II describes the motivation for the chosen study area. Section III continues with the details of the photogrammetric data processing. The output is further processed and analyzed in section IV and V, respectively modeling of urban expansion and viewshed analysis. This article ends with a conclusion and a short discussion on the findings.

II. STUDY AREA

The urban modelling focusses on five different study areas around the Pyramids of Giza (Figure1). This UNESCO world heritage site gets totally surrounded by the exploding city of Cairo. In the north and west direction Hada`iq al-Ahram or Pyramid Gardens where constructed since late the 1970s and this (in)formal development is still going on. Moreover the construction of the new Grand Egyptian museum will have a further impact on the view from and on the pyramid plateau since the concept of the winning design was a direct and uninterrupted view from the museum to the pyramids (Hansen, 2005). This area is directly related to the pyramid plateau. However other study areas are also processed. The second area is situated north of the Plateau where a lot of the hotels are located. As a third a historically more dense area around the Pyramid Road is taken. Furthermore an area near the Ring Road is chosen, because areas around such a road change rapidly (Darwish et al., 2007). The last study area is situated towards the south of Giza in a more rural environment.

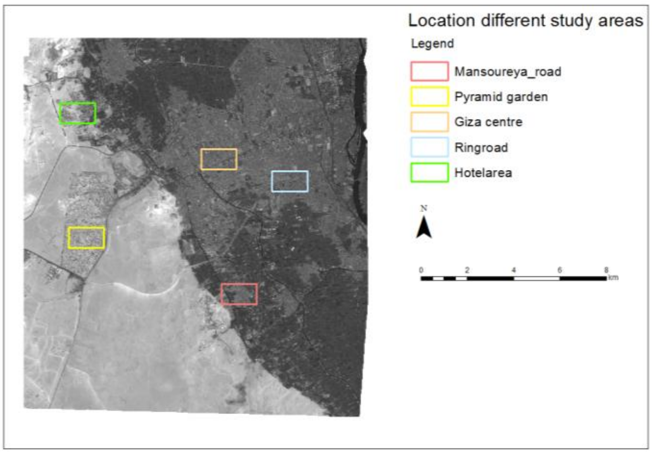

Figure 1. Location of the different study areas.

These different areas not only are chosen because they are under change and not far from the Pyramid Plateau but also because they have different city morphology. To quantify the differences, basic metrics are calculated on the most recent DSM, i.e. 2011. The application of a morphological filter to describe the diversity is well known (Zhang and Gruen, 2006). This method is further used by Stal et al. (2012) to quantify the specific diversity of the used study areas. They calculate a new cell value by taking a kernel around a pixel as a result of calculating the difference between the local minimum and maximum of all height values within this kernel. The results of the filter are listed in **Error! Reference source not found.** for this neighborhood data analysis a kernel size of 7 by 7 pixels is used taken into account that the DSM have a cell size of 0.5 by 0.5m. Here we can see that the variance is the biggest in the hotel area in contrast to the more rural area in the south which is more homogeneous.

TABLE I. STATISTICS OF THE NEIGHBOURHOOD DATA ANALYSIS

Area	**Statistics (m)**		
	Maximum	***Mean***	***Standard dev.***
Mansoureya	40.56	19.85	4.33
Pyr.Garden	128.68	97.08	9.04
Giza centre	71.94	33.74	11.45
Ringroad	66.87	27.41	8.83
Hotelarea	111.63	64.93	21.10

III. DATA PROCESSING

The data sets used to generate DSMs are stereoscopic panchromatic GeoEye-1 images from 2009 and 2011 with a GSD of 0.5m providing the most detailed images commercially available. . For 2009 only one stereo couple was acquired in contrast to the 2011 data wherefore two stereo couples were delivered covering the same area with a total surface of approximately 256km2. The Pyramid Plateau is situated in the center of the images as they cover west of Cairo, more specific Giza and its surroundings (Figure 1) and the accompanying satellite orientation files, i.e. Rational Polynomial Coefficient (RCP) files. GCPs were collected during field measurements in Cairo in January 2011. eATE makes it furthermore possible to generate a DSM on full resolution of the original images. As a result the output surfaces have a resolution of 0.5m for the 2009 and 2011 GeoEye models. The accuracy is calculated out of control and check points from the field campaign combined with automatically generated tiepoints in LPS and eATE software. The accuracy values of the final output surface models are within the range of 2-3 pixel value. These values are automatically accompanied with the output surface in eATE.The 2005 IKONOS images were covered with clouds. These areas were removed in the photogrammetric process, including the Pyramid Garden neighbourhood. As a result the 2.5 change detection is only processed by comparing the 2009 and 2011surface models.

TABLE II. ACCURACIES OF THE OUTPUT SURFACES

	Statistics (m)		
	RMSE	***Mean Error***	***LE90***
2005	0.522	0.020	0.858
2009	0.380	0.004	0.625
2011	0.366	-0.035	0.601

IV. MODELLING URBAN EXPANSION

These comparable and accurate high resolution DSMs enables the refinement of a change detection model. Although the availability of three DSMs in a time period of six years, only the two recent GeoEye DSMs are used to model the urban expansion around the pyramid.

The used 2.5 change detection method is adapted from Stal et al. (2013) In a first step a median filter with a five times five pixel kernel reduces the noise in the model caused by city furniture and other errors. Hereafter, a pixel-differencing detects the building changes between 2009 and 2011. To differentiate real changes from unchanged parts the differenced DSM needs to be threshold. The assumption that one building level is three meter high, results in two different datasets: one model with changes fewer than three meter, marking buildings that are remove and secondly a model with changes above three meter, marking constructed buildings and/or floors.

Morphological operations, in this case erosion followed by dilation, filters this binary raster data. This will remove linear artefacts and small clusters of pixels (Chaabouni-Chouayakh *et al.* 2010). The kernel used in a first approach is 20*20 pixels and corresponds with $100m^2$. The final change model is illustrated in Fig. 1 indicating in red the constructed buildings between 2009 and 2011 in a part of the Pyramid Garden area. The grey background illustrates the DSM created out of 2009 GeoEye-1 images.

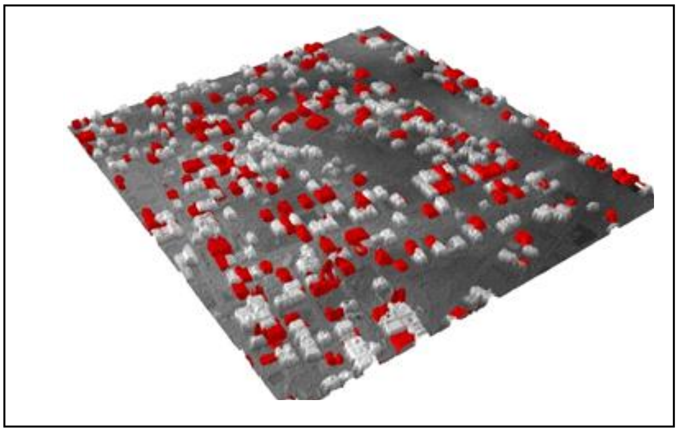

Figure 2. 2.5D view over a part of Hada`iq al-Ahram; new constructed buildings between 2009 and 2011 are marked in red.

V. VIEWSHED ANALYSIS

A further step to detect the urban changes in Giza is a viewshed analysis. High resolution digital surface models, created in the first step of this research are an essential tool for this. A direct view on the pyramids is popular in Giza. Not only because, apartments are sold “with a pyramid view” but also because the new Grand Egyptian Museum will have an uninterrupted view onto the plateau and its pyramids. The availability of three different DSMs gives the opportunity to analyse the evolution of the visual impact towards and from the pyramids in a period from 2005 until 2011.

VI. CONCLUSION

Using images with the highest resolution commercially available and accurate GCPs, it was possible to generate accurate and comparable DSMs which are essential for good change detection. Although the method of Stal et al. (2013) is based on Lidar and aerial images providing an even higher resolution and covering only a small area, we proved that the method can also be used for small scale satellite images. The method gives good indications not only where new buildings are constructed but also where new levels are added on top of existing apartment blocks. Due to different city morphologies, different thresholds have to be taken into account. However detailed statistics are not available thus some assumptions need to be made. We hope to integrate population statistics in a further step so that the resulting change model can be fine-tuned. These statistics are available on a certain level, however not on a neighbourhood level like our study area, Hada`iq al-Ahram.

The resulting model can give an idea how a city like Cairo is developing. Up-to-date statistics about population and households are hardly available. The combination of 2D information and building height information provides statistics about how many cubic metres built-up area is added through time and this can further be used to estimate population numbers. As a consequence local policy makers and international institutes like UNESCO can use these models to stabilise or control the urban expansion around the world heritage site.

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