

RESEARCH PAPER

The use of pixel-based algorithm for automatic change detection of 3D Building from Aerial and Satellite Imagery: Erbil city as a case study

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ABSTRACT:

Detection of Three Dimension (3D) changes and monitoring urban areas using photogrammetric and remotely sensed data is becoming an important research topic for monitoring the city development, disaster assessment, earthquake monitoring, and updating geo-database. In practice, identifying 3D changes manually in urban areas, specifically when dealing with a large number of buildings is considered to be a very time-consuming task, in such cases, automatic 3D change detection is considered to be very cost-effective. This paper presents an algorithm which is based on using pixels differencing to automatically detect 3D change of the buildings that occurred in the selected study area (Erbil city) for the periods from 2012 to 2017 by subtracting two digital surface models (DSMs) generated from two different datasets that has been captured from two different sensors. The first dataset is from stereo aerial imagery captured in (2012) and the second dataset is based on Very High Resolution (VHR) stereo satellite imagery captured in (2017). The proposed method is applied to three study areas (Ankawa, Dream city and 32 park) in Erbil city. Prior to applying change detection algorithm, the vertical accuracy of the DSMs is checked, through field point measurements by Differential GPS (DGPS).

The presented work in this article deals with building change detection. The changes that refer to differences in size and shape of buildings are considered significant, while changes in other urban objects, such as roads, ground and vegetation, are considered insignificant and needs to be removed. Through some post-processing steps that performed to preserve only the real changes and eliminate the virtual ones.

The outcome of this study revealed that for study area one (Ankawa), 105 out of 157 changed buildings are detected correctly. While in the study area two (Dream city) 74 out of 106 changed buildings are detected correctly, and for study area three (32 park) the result was more accurate and 28 out of 31 changed buildings are detected correctly.

KEY WORDS: DSM, stereo aerial imagery, 3D building change detection, very high-resolution stereo satellite imagery

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1.INTRODUCTION :

The process of identifying differences in the state of an object or phenomenon by observing it at different times is known as change detection (CD) (Singh, 1989).

The most dynamically changing areas on earth are specified to be in urban areas. Detection of urban changes is significant for a large number of organizations, such as local governments and municipalities, for various applications including updating maps and managing emergency issues, such as earthquakes or floods.

Generally, remote sensing data is primary sources that is widely used for detecting changes. Recently, because of the steady technology development of sensors, platforms, and algorithms

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for 3D data acquisition and generation, the decision-makers can quickly identify the changes in the area of interest.

Monitoring the changes in Earth's surface features is a significant task, therefore, change detection techniques are an active topic by researchers. Various techniques have been developed to accommodate user requirements in an attempt to overcome the difficulties that arises during the process and provide accurate results for change detection (Lu *et al.*, 2004).

Kurdistan Region of Iraq and particularly Erbil city has a significant urban growth since the year 2000, and the total cultivated land decreases annually, because land transformed to relevant build-up area due to urban growth Erbil city (Ibrahim, 2015). Therefore, automatically detecting building changes is a critical need to measure the amount of changes rapidly.

Different researchers focused only on 2D data that extracted from satellite images for change detection purposes such as (Im *et al.*, 2008, Sadeq, 2009, Bouziani *et al.*, 2010, Champion *et al.*, 2010). However, 2D change detection can extract horizontal changes in planimetric direction, especially in order to detect the object's changing size in planimetric space. These results are not sufficient for applications where the vertical change are required, such as progress monitoring for building construction and quantitative estimation of landslides volume (Qin *et al.*, 2016).

3D change detection is considered to be more robust than 2D change detection, because 2D change detection strongly affected by illumination and atmospheric conditions (Tian, 2013). For example, two satellite images are available for the locations where no changes have occurred. One is from the (early summer) where fields and bare soil are visible, while the other is from the (winter) that most of the unsealed area is snow-covered. In such cases when 2D change detection algorithms are adopted by comparing only the spectral images, it would lead to large areas of change because they share different radiometric resolution coming from seasonal differences, which make a false positive in change detection process. Therefore, height is a very important feature in such cases for highlighting the vertical changes. In this research the height information is addressed

in change detection which is extracted from the DSMs to determine 3D changes.

Various researcher used 3D change detection based on using Digital Surface Model that derived from Light Detection and Ranging (LiDAR) such as (Murakami *et al.*, 1999, Benedek and Szirányi, 2009, Choi *et al.*, 2009). The 3D change detection is considered to be more accurate but has the limitation of being more expensive and exhibit a low temporal repetition rate. While, in most situations, satellite stereo data are usually much faster, easier, and less expensive to acquire.

Most of the previous studies used only one type of the optical sensor to determine 3D changes (Krauß *et al.*, 2007, d'Angelo *et al.*, 2008, Tian, 2013, Tian *et al.*, 2014). In this research work two different optical sensors used to determine the building changes, one is specified to be derived from aerial sensors which provide 0.1 m Ground Sample Distance (GSD) resolution and satellite sensor which has 0.5 m GSD. The data are captured at two epochs (approximately 5 years difference). Thus, two different DSMs are generated and then subtracted from each other using pixel based images differencing algorithm to determine building changes. The applied techniques in this research can be implemented for municipality works such as illegal housing detection when building structures are constructed in forbidden areas, or during the war when government needs a rapid damage assessment of the impacted areas. As well as it can be used for planning purposes.

2. METHODOLOGY AND MEASUREMENTS

2.1 Study area and Dataset

A study area of 5× 5 km square that had a significant urban development in Erbil city is selected. The methodology is examined in three test areas located within that selected area: Area 1 (ankawa), Area 2 (dream city) and Area 3 (32 park). The first group of the data set consists of a very high resolution stereo satellite imagery of world view-02 (WV02) in year (2017). As shown in the figure (1)

The WV02 satellite was launched by DigitalGlobe at 2009, the images consisted of eight band multi-spectral images, where a set of four new bands (coastal, yellow, red edge and NIR2) are added to the usual four bands (red,

green, blue, and NIR1) with resolution 2 m and one panchromatic band with resolution 0.5m (Konstantinidis, 2017).

The second group of data set is a very high resolution aerial imageries of Erbil city at year (2012) with 0.10m GSD resolution were provided by the photogrammetric labs of Geomatics

(surveying) engineering department-college of Engineering. The aerial imageries were acquired by Ultracam Xp sensor with 100.5mm focal length at an altitude of 2195m above MSL, and table-1 presents the characteristic of used aerial images in each case study.

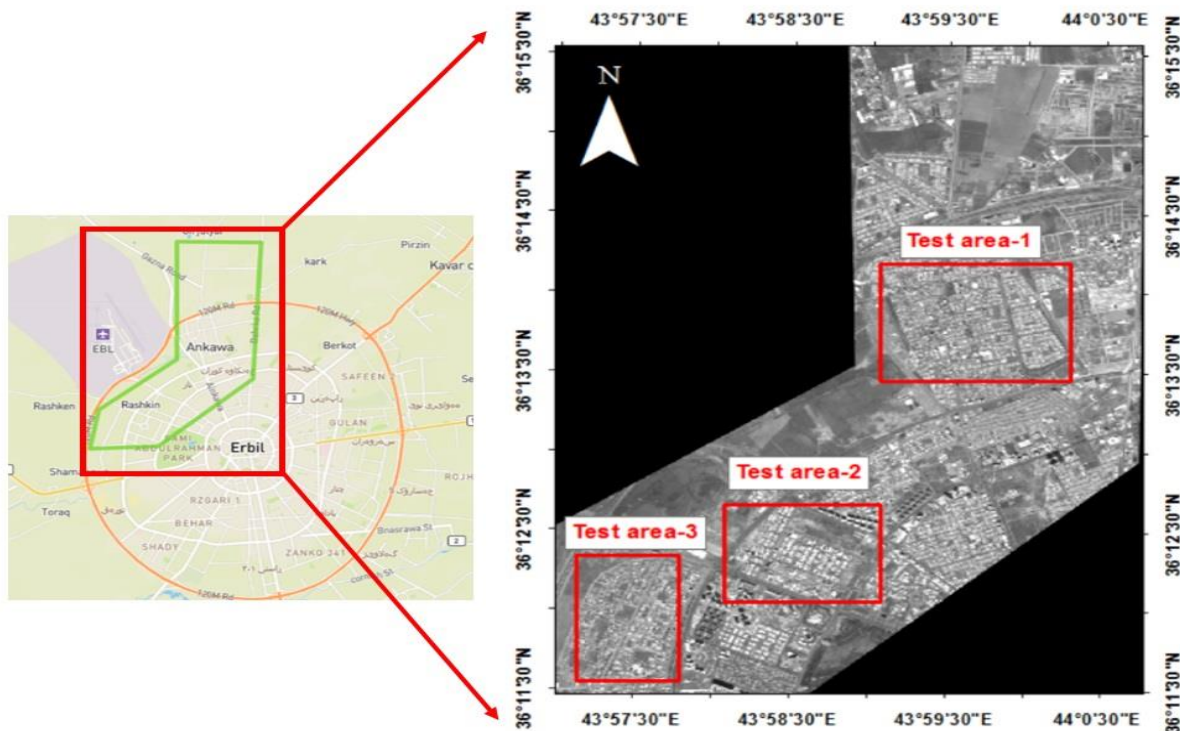


Figure (1): The location of three test areas on the VHR stereo satellite images

Table (1) technical characteristic of the aerial image data used in this research

Test areas	Image ID	Xs	Ys	Zs	OMEGA	PHI	KAPPA	Overlapped Area	GSD
Test area.1	10_0521	409642.0549	4009941.9519	2587.7359	-0.1444	-0.1094	-179.7243	%60 %30	10cm
	10_0522	409640.0010	4010422.5094	2587.7704	-0.0904	-0.0819	-179.8258		
Test area.2	09_0442	408386.4046	4007322.6850	2593.9523	-0.0100	0.1988	0.1317	%60 %30	10cm
	09_0442	408385.4408	4006840.4430	2594.1559	0.0223	0.1600	0.1486		
Test area.3	08_0390	407118.1138	4006727.4551	2593.3563	-0.0564	-0.0817	-179.8687	%60 %30	10cm
	08_0391	407116.7327	4007214.2485	2592.9113	-0.0706	-0.0859	-179.8242		

2.2 Measuring Ground Control Point (GCP)

A set of GCPs is measured for the processing purpose of the satellite and aerial imagery and for the purpose of evaluating the accuracy. The data are collected by using Leica-1200 GPS instrument, at the beginning one hour observation for the base station was carried out via a static method. Then the GCPs were observed through the GPS post processing kinematic (PPK) technique. This technique is used to locate positions whereby received signals from a movable location (rover) to the receiving device (base) then stores position data that can be adjusted by the use of corrections from a reference station after the data collection process. During the observation, the base station took a

measurement consciously for seven hours, and the required observation for each rover stations is approximately three minutes. The GCPs are acquired with Universal Transverse Mercator (UTM) zone 38N projection and WGS 84 datum, later the GPS points are imported to Leica geo-office software for post processing purpose and they are processed based on the nearest Continuously Operating Reference Station (CORS), which was Iraq Survey Erbil (ISER) as a source of GPS corrections the result, relative to the base station, was thirty GCPs within millimeters accuracy. Based on the study areas several GCPs are used as checkpoints to assess the accuracy of generated DSMs, figure (2) presented location of GCPs with green dots.

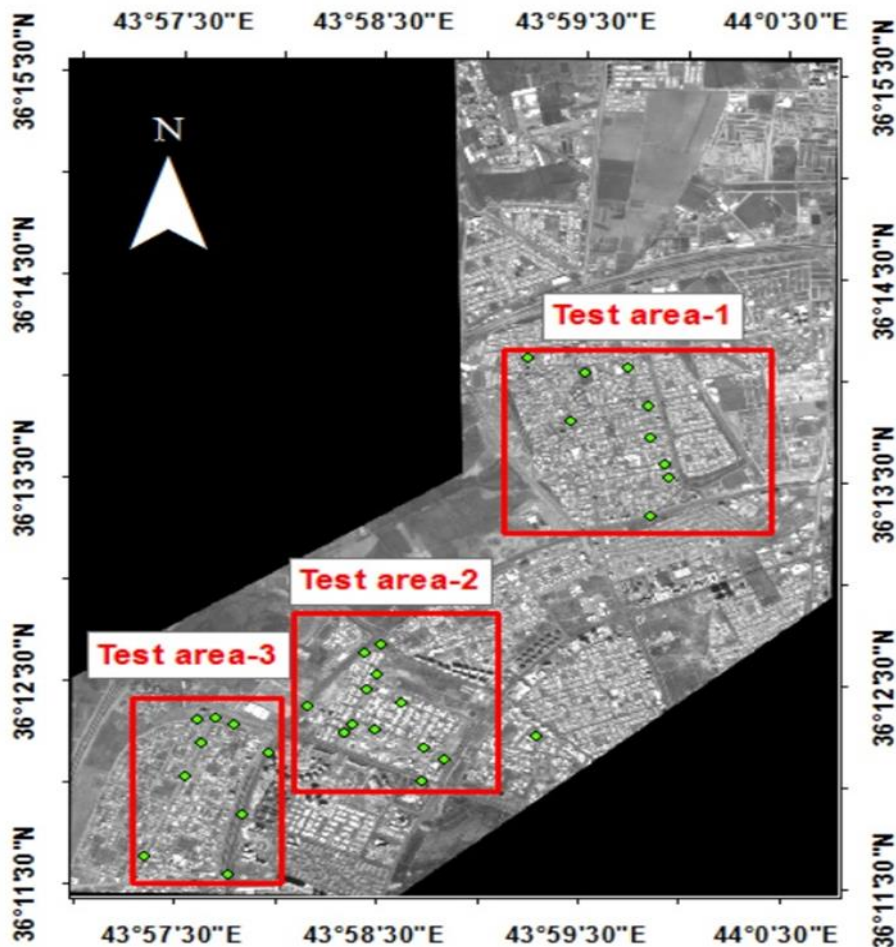


Figure (2): location of the GCPs presented by green dots

2.3 Data Processing and DSM generation

In this study the stereo aerial and satellite imageries are processed through the use of a full featured remote sensing software known as ERDAS Imagine. The package includes Leica photogrammetry suite (LPS) with all the basic photogrammetric tools, it is used to generate DSM from worldview-2 stereo pair data and Aerial images for all three test areas. The flow charts of generating DSM in LPS for both data sets are described in figure (3).

The first step of generating DSM in LPS starts by describe a block file, for the stereo pair satellite images which defining the geometric model of the image through Rational Polynomial Coefficient (RPC) model and the projection. As Worldview-2 stereo images are provided with RPC within Rational Function (RF) sensor model. RPC file contains information about the interior and exterior orientations. The accompanied files are considered to be very useful since it minimizes the time for image processing due to not having to embark on the interior and exterior orientation processes (Sadeq, 2015). Then the block project is assigned by the vertical and horizontal coordinates with UTM projection and WGS 84 datum zone 38N. The two stereo images are added to the block file.

For the aerial images the block file creation starts with adding the parameters of the geometric model of the camera to define the interior orientation. The interior orientation describes the internal geometry of the sensor as it was during

image capture while exterior orientation is the sensor position and its orientation, at the time of image capturing (Sadeq, 2015). Followed by, assigning the coordinate system to the UTM zone 38N projection and WGS 84 datum to the block file, the parameters are defined from the camera calibration Report, which is provided by the Manufacturer: Vexcel Imaging GmbH, A-8010 Graz, Austria. Then for each study area, one stereo pair which consisted from two aerial images are added to the block file.

Later, start the tie point generation and bundle block adjustment which lead to the completion of exterior orientation, all these processes are achieved in the LPS software environment. The LPS software supports both manual and automatic tie points generation. The ground coordinates of tie points are not known, but the points are visually recognizable within the overlapping areas of image pairs. LPS selects a matching point in one image, finding its conjugate point in the other (stereomate) image, to measure the similarity between the image points appearing in the overlapped area (Saha, 2014). The Ground coordinates for tie points are computed during block (or aerial) triangulation, where LPS offers the use of different models to optimize the result of aerial triangulation, such as bundle block adjustment (BBA). The BBA uses the collinearity condition as the basis for formulating the relationship between image space and ground space (Geosystems and Mapping, 2003).

A bundled solution is computed including exterior orientation parameters of each image in a block and the X, Y and Z coordinate of tie points.

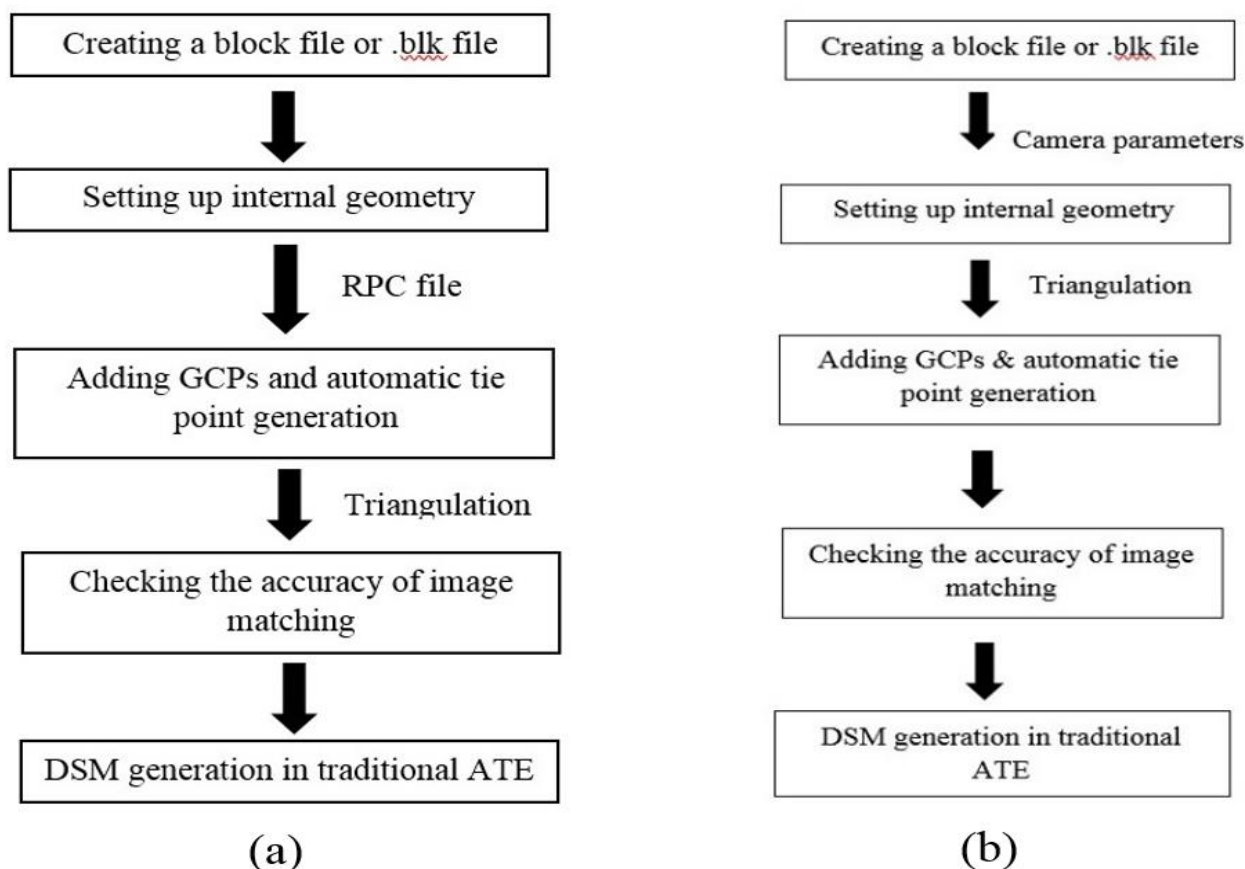


Figure (3): flow charts showing the steps of generation DSM (a) for stereo satellite and (b) for Aerial images

2.4 DSM generation

The DSM is obtained by using classical photogrammetric approach in LPS which is done by image matching process using least square (LS) matching algorithm. Its idea is based on minimizing the differences in grey values between the reference window and search window in an adjustment process where geometric (location, size, and shape of the search window) and radiometric (pixel gray values) corrections of one of matching windows are determined (Schenk, 1999). Least squares correlation is iterative process. The parameters calculated during the initial pass are used in the calculation of the second pass and so on, until an optimum solution is determined. Least square matching technique is the most accurate image matching technique, and

the location of the match can be estimated with an accuracy of up to 0.01 pixels (Geosystems and Mapping, 2003).

Finally, the obtained results from LPS processing were six DSMs with 0.30m grid cell size, produced from optical stereo aerial and stereo satellite images. Later the produced DSMs are resampled to 1m grid cell size in order to have the same cell resolution with Normalized Differenced Vegetation Index (NDVI) mask that mentioned in the section 3, because when there is a processing between multiple raster datasets, they need to be stored with the same cell resolution.

Hence, the DSMs from aerial and satellite images for three selected study areas have been generated and shown in figure (4).

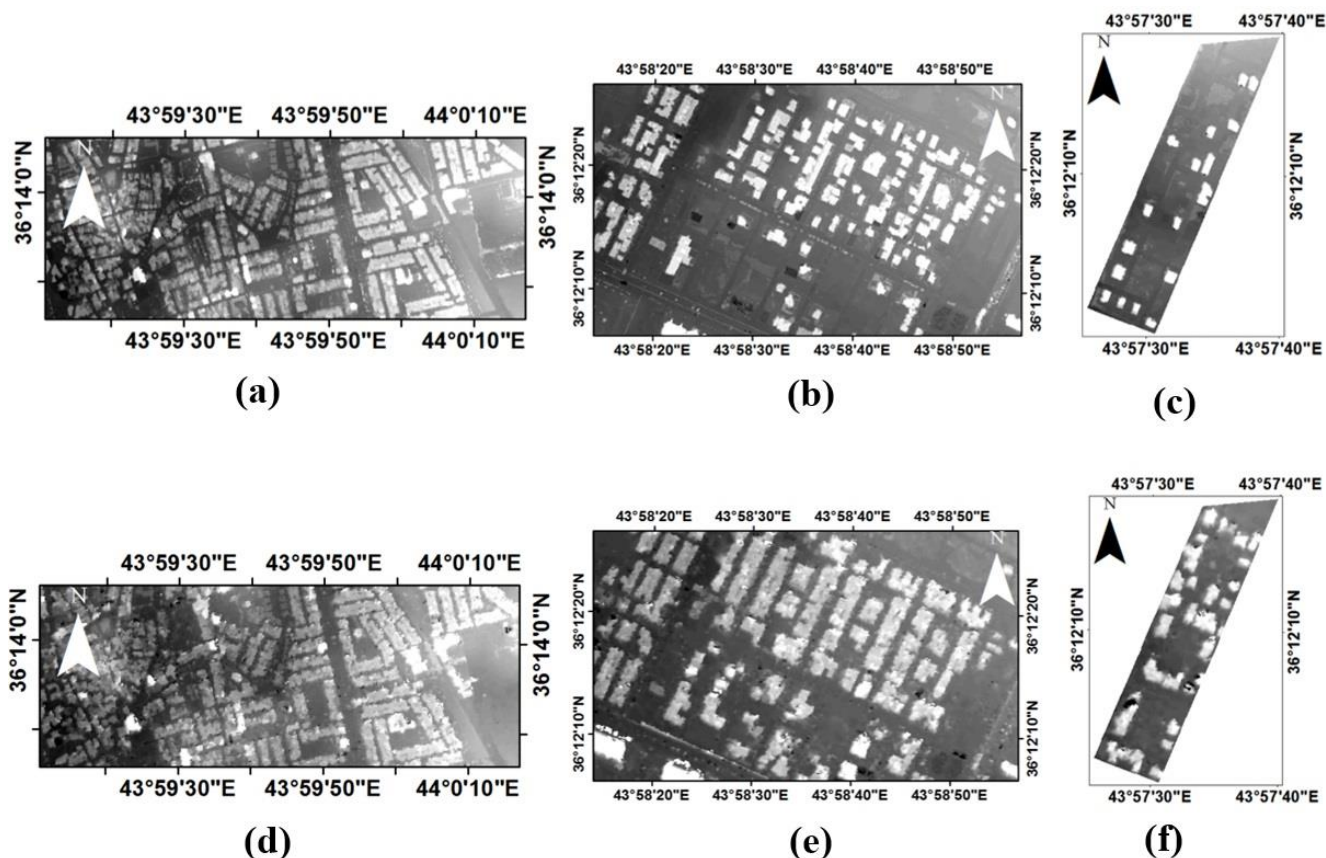


Figure (4) DSMs have been produced for the three study areas, (a, b and c) represents Aerial DSMs - 2012 for test area (1, 2&3) respectively, while satellite DSMs-2017 represented by (d, e and f).

3. APPLYING CHANGE DETECTION

Pixel-based image differencing algorithm determines the magnitude of change per pixel between two compared images independently without taking into consideration the pixel neighborhoods. Pixel-based algorithms are fast and easy to implement but suffer from the effect of noise, shadows and illumination variations (Konstantinidis, 2017).

In this study, to perform change detection process, an image differencing algorithm by MATLAB is used to apply on the generated DSMs from date (2012) to the (2017). The flow chart of this pixel-based 3D change detection algorithm is illustrated in figure (5).

The elevation values from the generated DSMs are subtracted, pixel by pixel for computing new binary change map to determine building heights as follow:

$$\text{If } \text{DSM}_2(i, j) - \text{DSM}_1(i, j) \geq T \quad \text{BC}(i, j) = 1 \text{ (changed pixel)} \quad (1)$$

$$\text{If } \text{DSM}_2(i, j) - \text{DSM}_1(i, j) < T \quad \text{BC}(i, j) = 0 \text{ (Unchanged pixel)} \quad (2)$$

Where: DSM_2 is satellite DSM-2017, DSM_1 is Aerial DSM-2012, i and j are line and pixel numbers in the DSM images, T is the threshold value, BC is the new binary change map

The obtained binary change map is given in Figure (6) as it shows BC for all test areas.

By subtracting the generated DSMs from each other, the differences in the height of the buildings or urban features are detected. However, some virtual changes that are not belong to the buildings have appeared also. These objects are removed through three steps. First, thresholding is applied as $T=2m$ determines so that height differences less than a threshold value T are considered as computation errors and removed. afterward, the obtained thresholded map is binarized into black and white, where black pixel represents unchanged area while white pixel represents changed area that there changed value is more than 2m.

From the result, it is noticed that the thresholding step succeeds to eliminate most of the virtual changes resulting from DSM computation errors. Nevertheless, some virtual changes do still remain and need to be removed, since the main interest of this paper is only on 3D building changes so the elimination of the vegetation from the 3D change detection scheme is essential. Therefore, in the second step, NDVI mask is calculated from the near-infrared and visible light reflected by vegetation from stereo satellite images as it is given in equation (3). Then NDVI mask subtracted from the binary change map.

$$NDVI = (NIR - VIS) / (NIR + VIS) \quad (3)$$

Where: NIR and VIS stand for the spectral reflectance measurements acquired in the near-infrared and visible (red) regions, respectively (Herring, 2000).

Spurious change in altitude can also be caused by other land covers or DSM computation errors. Building change extraction results will be affected by this type of changes, as they are displayed often around the buildings, therefore, more adaptive post-processing steps are required to keep only the real changes. The final step is applying some mathematical morphology operations, opening followed by closing. Where the mathematical morphology is a non-linear process that commonly used in image analysis which is based on modifying the geometrical shapes within the image, rather than pixel values (Sadeq, 2015).

Based on the test areas the choice of the kernels size for opening and closing operation are carefully done to keep most of the real changes and remove most of the virtual ones, in order to make the real changes more compact and the virtual ones thinner. Figure (6) shows a cleaner final change map.

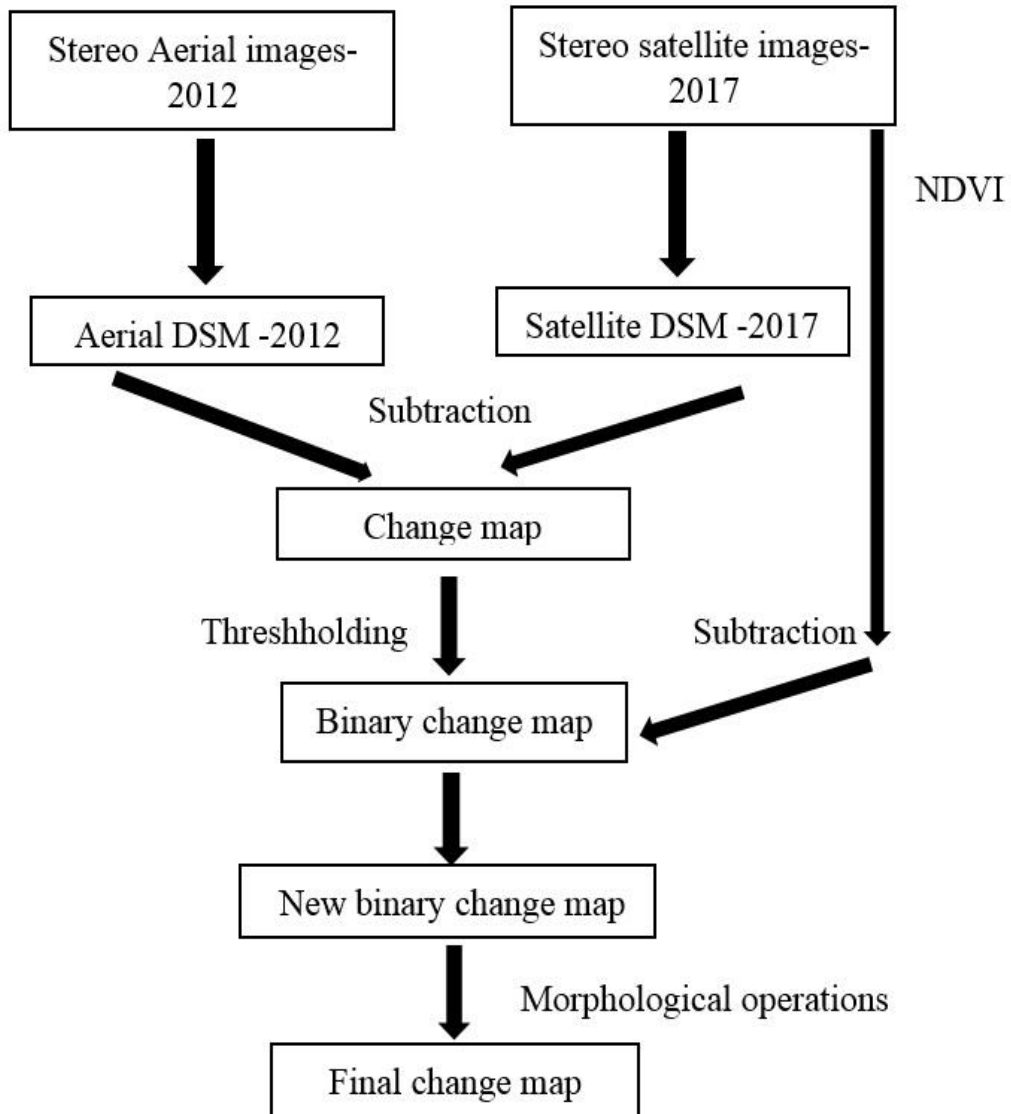
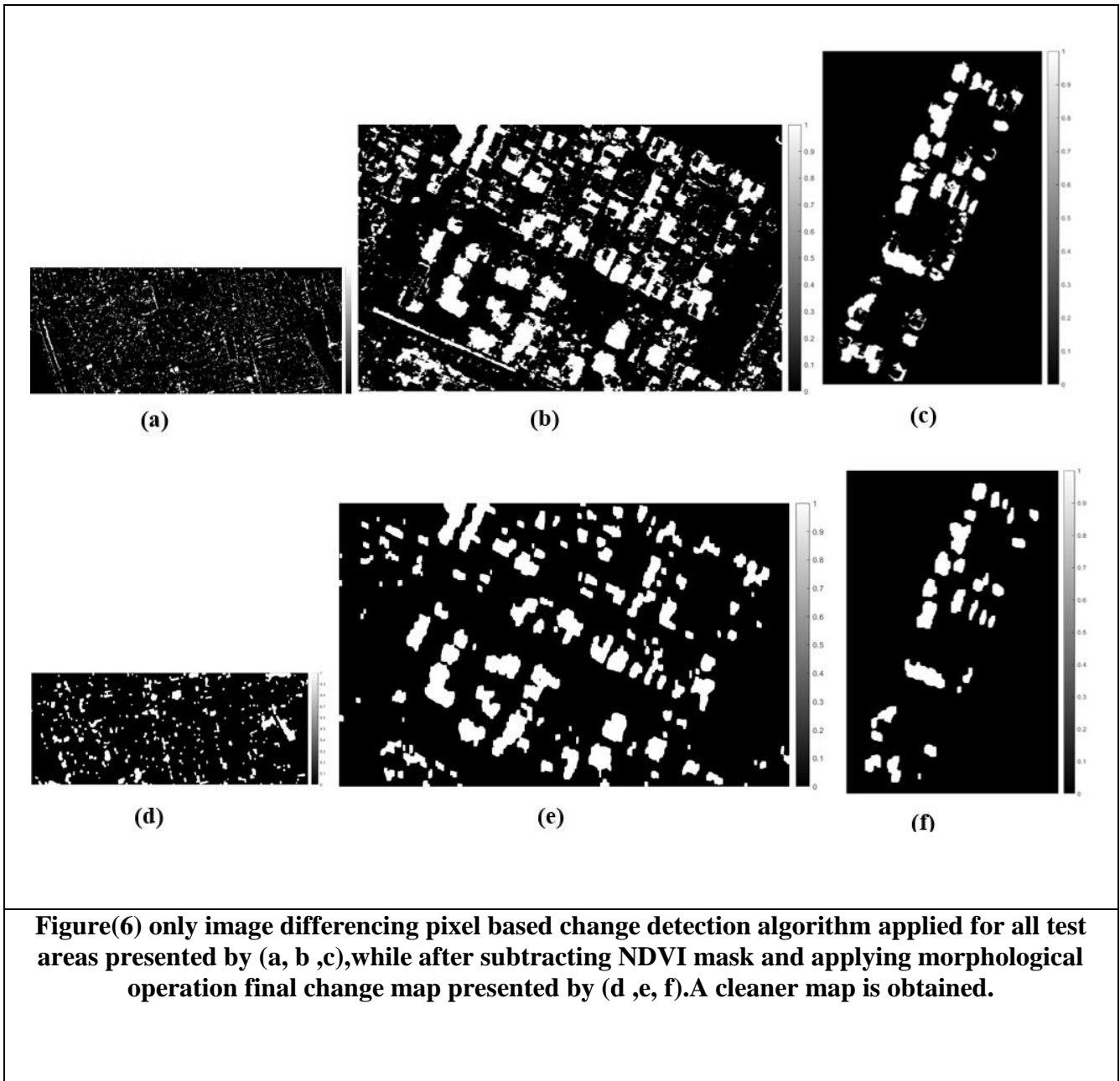


Figure (5) flowchart of the pixel based 3D change detection approach



4. RESULTS AND DISCUSSION

The change detection results based on the pixel-based image differencing algorithm was examined on three areas (1, 2 and 3). For selected study areas, the building outlines are appeared sharp in the aerial DSMs, while they are quite smooth in the satellite DSMs and showed fewer details than the aerial DSM as it's shown in Figure (4), the reason is the GSD resolution of the aerial DSM is (0.1m) which is higher than the satellite DSM as its (0.50m), so its effect the quality of generated DSMs. Also, a simple difference

between generated DSMs at different times is not sufficiently robust to detect the real changes as it is presented by (a, b and c) from figure (6).From the change detection result the vegetation growths are detected as 3D changes, therefore NDVI mask is applied to eliminate the vegetation from the change map. It's seen in figure (7). Also, the existed noise coming from sensor variations and different resolutions are already eliminated by applying some post processing steps in MATLAB software and a cleaner change map obtained as presented in figure (6-d, e, f).

It can be seen from figure (8-a) that a concrete foundation is obviously visible in the center of aerial image 2012. While figure (8-b) a new building can be recognized in the satellite image 2017, which was built on the concrete area, so there is the possibility that the roof top of a new building and the previous concrete floor consist of similar material: therefore, they will share similar radiometric characteristics and even similar texture. In such a cases if only 2D information extracted from satellite and aerial images used to determine changes, the changes in vertical direction are easily overlooked. Thus the height information from a DSM plays an important role in this domain.

For test area two (dream city) from figure (6-e), there is larger urban growth than the test area one, and study area three (32 park), as it's presented in figure (6-f), a smaller area selected in order to show building changes clearly. The outcome result presented in Table-2 shows a good performance for the test area (3) and medium performance for the test area (2). The reason is that in this test area, with 5 years of time difference, some buildings have been reconstructed with a similar height at nearly the same place as the former buildings. In this case, height change is not really helpful.

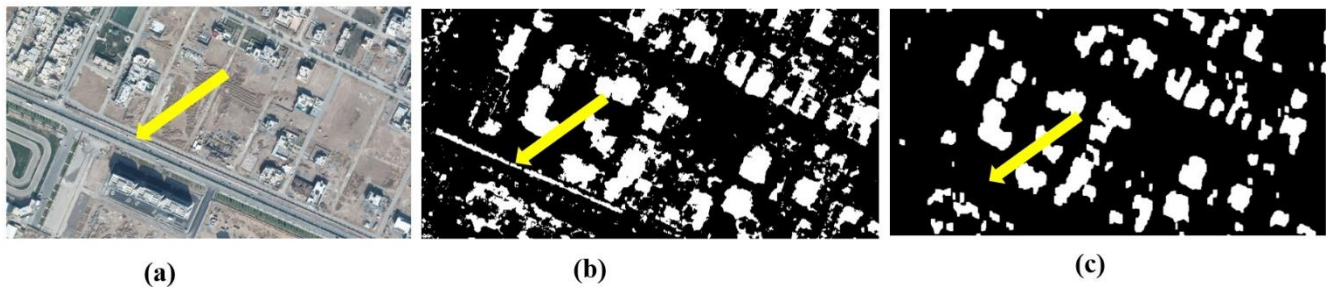


Figure (7) (a) vegetation location in Aerial image marked by the yellow arrow (b) pixel base change map result (c) vegetation removed after subtracting NDVI from the change map

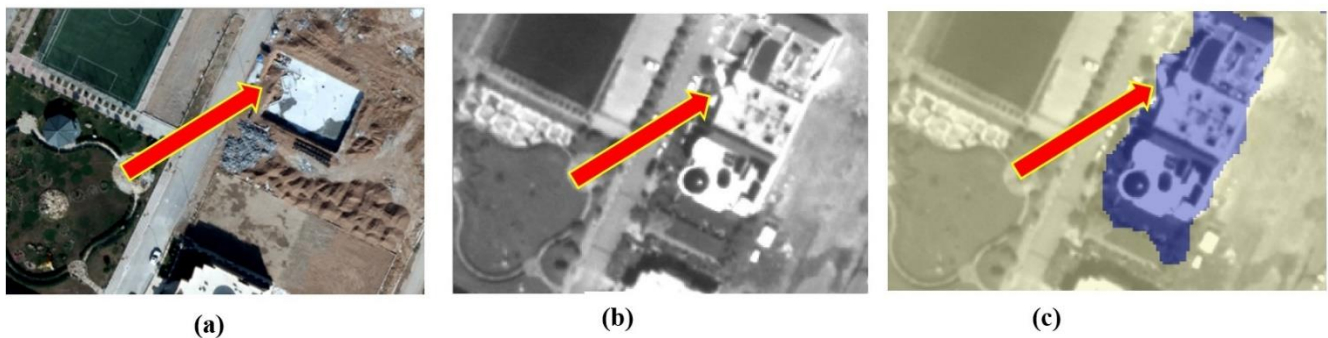


Figure (8) (a) a concrete foundation on Aerial image from (2012), (b) a constructed building on satellite image from (2017) .Also (c) represents the correctly detected 3D building changes without being overlooked.

Table (2) accuracy assessment of each study area based on pixel based change detection algorithm

Test areas	True detected number(TDN)	False detected number(FDN)	Total changed object number(N_T)	True detected rate	False detected rate
Test area-1	105	52	157	%67	%33
Test area-2	74	32	106	%70	%30
Test area-3	28	3	31	%90	%10

4.1 Accuracy assessment

The vertical accuracy of the aerial and satellite DSMs are checked prior to applying change detection it is achieved by comparing the computed Z-coordinate values at checkpoints with the same points on generated DSMs the root mean square error (RMSE) were calculated for each test areas. The result for study area (1,2,3) from aerial DSM were (0.23 m,0.39 m,0.52 m) respectively, and from satellite DSMs were (0.41 m,0.48 m,0.23 m) respectively.

Also, for change detection accuracy assessment, quantitative analysis is applied to check the success rate by overlay the final change map result with the ortho-images generated from aerial DSMs and projected satellite images using arc map software to compare and analysis the result as shown in figure (9) . Moreover, for evaluation pixel based change detection result four indices are measured:

1. True detected number (TDN): The changed objects number that correctly detected as changed.

2-True detected rate (TD): The percentage of the true detected objects number is given in equation (4).

$$TD = TDN/N_T \times 100 \quad (4)$$

3. False detected number (FDN): The unchanged objects number that incorrectly detected as changed.

4. False detected rate (FD): The percentage of the false detected objects number is given in equation (5).

$$FD = FDN/N_T \times 100 \quad (5)$$

Where N_T is the total changed objects number. The evaluation result for all test areas presented in table-2.

From the visual inspection of the achieved results, it has shown that DSMs generated from optical stereo imageries could be reliable sources for efficient 3D change detection. However most of the changes are correctly detected, some wrongly detected building changes appeared within the study areas, and they are eliminated through the post processing steps. An example of false and truly detected change result is illustrated in figure (10).



Figure (9) (a) satellite image, (b) ortho image generated from Aerial images, (c) binary change map layer. All layers are overlaid using arc map software

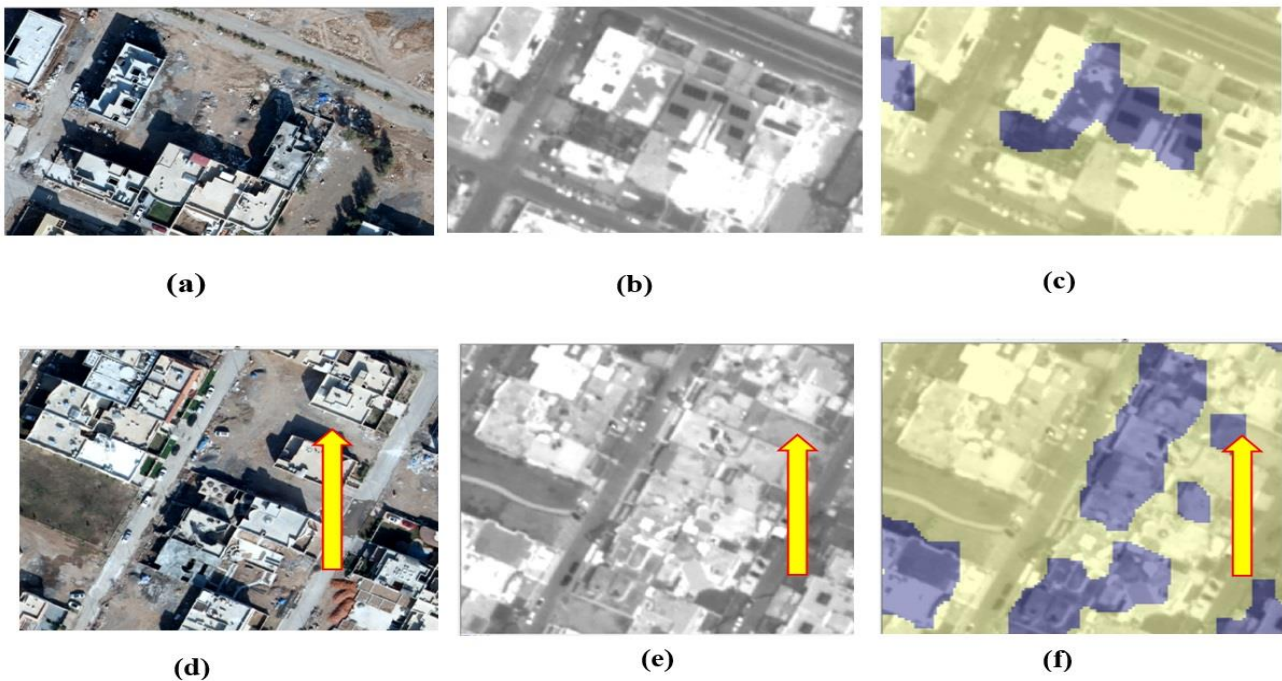


Figure (10) (a) ortho aerial images-2012,(b) satellite image-2017,(c) truly detected change detection result ,(d) ortho Aerial image-2012,(e) satellite imag-2017,(f) false detected change area where selected area by yellow arrow on the images(d,e) is unchanged, while its considered as changed in (f)

5. CONCLUSIONS

Height information plays an important role in monitoring city development, especially, it is helpful for detecting building changes. Most of the previous 3D change detection approaches prefer LiDAR data, which are more accurate but have the drawback of being more expensive and exhibit a low temporal repetition rate. While, in most situations, satellite stereo data are usually much faster, easier, and less expensive to acquire.

Height information from DSM is particularly crucial for change detection of objects exhibiting height values above the ground such as tree or buildings, and the quality of the generated DSMs will be influenced based on the used datasets. However, most of the studies used to determine 3D changes, are addresses only one type of optical sensor used as mentioned in section 1 (introduction). In this research two different optical sensors are used. One is specified to be from an aerial optical sensor which provides 0.1 GSD resolution and the other is from the satellite sensor with 0.50 GSD resolution. The generated DSM from aerial images provide more detailed information than the DSM from stereo data.

In this research, the obtained result for test area one (Ankawa) out of 157, the changed buildings that are detected correctly were 105. While in the test area two (Dream city) 74 out of 106 changed buildings are detected correctly, and for test area three (32 park) the result was more accurate and 28 out of 31 changed buildings are detected correctly.

Finally, it can be concluded that manually selecting the threshold value for the change map should be carefully done, which affects the results in several procedures. Also it is noticed that a simple DSM differencing at different times is not sufficiently robust to identify the real changes, therefore, some post-processing steps are required to keep the real changes and eliminate the virtual ones caused by the DSM computation error and also from different nature of the DSM sources.

REFERENCES

- BENEDEK, C. & SZIRÁNYI, T. 2009. Change detection in optical aerial images by a multilayer conditional mixed Markov model. *IEEE Transactions on Geoscience and Remote Sensing*, 47, 3416-3430.
- BOUZIANI, M., GOÏTA, K. & HE, D.-C. 2010. Automatic change detection of buildings in urban environment from very high spatial resolution images using existing geodatabase and prior knowledge. *ISPRS Journal of Photogrammetry and Remote Sensing*, 65, 143-153.
- CHAMPION, N., BOLDO, D., PIERROT-DESEILLIGNY, M. & STAMON, G. 2010. 2D building change detection from high resolution satellite imagery: A two-step hierarchical method based on 3D invariant primitives. *Pattern Recognition Letters*, 31, 1138-1147.
- CHOI, K., LEE, I. & KIM, S. 2009. A feature based approach to automatic change detection from LiDAR data in urban areas. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci*, 18, 259-264.
- D'ANGELO, P., LEHNER, M., KRAUSS, T., HOJA, D. & REINARTZ, P. Towards automated DEM generation from high resolution stereo satellite images. *International Society for Photogrammetry and Remote Sensing*, 2008. 1137-1342.
- GEOSYSTEMS, L. & MAPPING, L. 2003. Leica photogrammetry suite orthoBASE and orthoBASE Pro user's guide. *Leica Geosystems GIS and Mapping, LLC, Atlanta, GA, USA*.
- HERRING, J. W. A. D. 2000. *earthobservatory* [Online]. Available: https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring_vegetation_2.php [Accessed 18th may 2019].
- IBRAHIM, G. R. F. 2015. *Urban Expansion Monitoring in Erbil City. Utilizing Remote Sensing tools in the Kurdistan Region*, GRIN Verlag.
- IM, J., JENSEN, J. & TULLIS, J. 2008. Object-based change detection using correlation image analysis and image segmentation. *International Journal of Remote Sensing*, 29, 399-423.
- KONSTANTINIDIS, D. 2017. Building detection for monitoring of urban changes.
- KRAUB, T., REINARTZ, P., STILLA, U., MAYER, H., SCHMITT, M., JUTZI, B. & ROTTENSTEINER, F. 2007. Extracting orthogonal building objects in urban areas from high resolution stereo satellite image pairs. *Int. Arch. Photogrammetry, Remote Sens., Spatial Information Sc*, 36, 3.
- LU, D., MAUSEL, P., BRONDIZIO, E. & MORAN, E. 2004. Change detection techniques. *International journal of remote sensing*, 25, 2365-2401.
- MURAKAMI, H., NAKAGAWA, K., HASEGAWA, H., SHIBATA, T. & IWANAMI, E. 1999. Change detection of buildings using an airborne laser scanner. *ISPRS Journal of Photogrammetry and Remote Sensing*, 54, 148-152.

- QIN, R., TIAN, J. & REINARTZ, P. 2016. 3D change detection—approaches and applications. *ISPRS Journal of Photogrammetry and Remote Sensing*, 122, 41-56.
- SADEQ, H. A. 2009. City Growth Monitoring Using Map and Remote Sensing: Case Study Arbil-Kurdistan. *ZANCO Journal of Pure and Applied Sciences.*, 21, 8.
- SADEQ, H. A. 2015. *Merging digital surface models sourced from multi-satellite imagery and their consequent application in automating 3D building modelling*. University of Glasgow.
- SAHA, K. 2014. DSM extraction and evaluation from Cartosat-1 stereo data for Bhopal city, Madhya Pradesh. *International Journal of Scientific and Research Publication*, 4, 1-5.
- SCHENK, T. 1999. *Digital photogrammetry: Vol. I: Background, fundamentals, automatic orientation produceres*, TerraScience.
- SINGH, A. 1989. Review article digital change detection techniques using remotely-sensed data. *International journal of remote sensing*, 10, 989-1003.
- TIAN, J. 2013. *3D change detection from high and very high resolution satellite stereo imagery*. Universität Osnabrück.
- TIAN, J., CUI, S. & REINARTZ, P. 2014. Building change detection based on satellite stereo imagery and digital surface models. *IEEE Transactions on Geoscience and Remote Sensing*, 52, 406-417.