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EVALUATION OF HEIGHT ACCURACY FROM HIGH RESOLUTION WORLDVIEW-3 STEREO SATELLITE IMAGERY

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ABSTRACT

Topographic variation description obtained from topographic maps or Digital Elevation Models (DEMs) is quite commonly used for several applications especially in the fields of Geographic Information Systems (GIS) and civil engineering projects. Many procedures are now used to prepare height data for topographic maps and DEMs formation. These include classical ground surveying methods: levelling plus triangulation or traversing, total station and stereo images from air photos captured by aerial and drone cameras. All these techniques would give very high accurate elevations, but they are very much time consuming and labor intensive. Recent techniques use space stereo imageries to produce ground point elevation. One of the high resolution satellite imageries (HRSI) capturing stereo images is the satellite borne WorldView-3 (WV-3). Although such remote sensing methods save a lot of time and expenditure the limitation is the height accuracy obtained. This paper analyze (instead of compares) the elevation accuracy. that can be derived from WV-3 stereo imagery using elevations determined by total station as reference. Test results show that WV-3 stereo imagery can allow height accuracy that can be used for several applications including production of 1:5000 scale topographic maps, saving both money and time.

INTRODUCTION

Topographic maps and Digital Elevation Model (DEM) are widely used for earthwork calculations in route construction, hydrologic and geologic analysis as well as in channel networks, drainage basins and morphological studies (Balasubramanian, 2017). These as well, can be considered as the most important tools and applications in Geographic Information Systems (GIS) since they provide a three dimensional view of the earth's terrain and can be linked to the earth's physical processes, like water infiltration, overland flow, floods and vegetation distributions. This is because the models used to drive these processes are all based on three dimensional data (Thursonand Ball, 2007).

Methods for obtaining elevation data include ground point spot height collection techniques such as differential levelling, total station, real time kinematic global positioning system (RTK-GPS), remote sensing techniques including stereo photogrammetry from aerial photographs, stereo photogrammetry from drones, light detection and ranging (LiDAR) and interferometry from radar data. For a long time aerial photographs have been considered as the dominating source of elevation data for topographic mapping and DEM covering vast areas. The disadvantage, however, of stereo-photogrammetric DEM production is the added expense of acquiring ground control points (Balasubramanian, 2017).

LiDAR uses a laser to emit tens of thousands of light pulses from the bottom of the aircraft towards the surface of the Earth and after bouncing back the range between ground surface and the aircraft can be determined. Precise positional data of the airborne sensor platform from onboard GPS and inertial measurement units, which measure the attitude of the aircraft, are critical for the calculation of three dimensional coordinates of ground points. This technique is efficient in mapping relatively large areas, such as cities or counties. It can also be operated any time day or night. The only major disadvantage of the technique is that the resulting dense point cloud of three dimensional measurements is difficult to interpret.

IFSAR (Interferometric Synthetic Aperture Radar) mapping is another active sensing data collection technology in which radar pulses, typically X-band, are emitted from the spacecraft or aircraft down towards the Earth's surface. These radar signals reflect off the surface and return valuable information content to a receiving antenna. The phase difference measured in the return signal yields accurate three dimensional ground coordinates. A major limiting factor when using this technique is the phase delay or advanced caused by the medium through which the radar signal is travelling (Bekaert, et al, 2015).

Recently high-resolution optical imaging satellites such as SPOT-5, 6, 7, IKONOS, QUICKBIRD, ORBVIEW, EOS-1, Geo Eye, WorldView1, 2,3 and Pleiades are considered as the most powerful remote sensing data source for the generation of DEMs for vast areas of the Earth's surface. See for example: Deilami and Hashim, 2011; Agugiaro, et al, 2012; Yanalak, et al, 2012; Capaldo et al, 2012; Aguilar, et al, 2014; Nasir, et al, 2015; Barbarella, et al, 2017; Elkhrachy, I. 2018; Wang, et al, 2019.

One of these recent very high resolution stereo satellite imageries (30cm ground resolution) that can be used for creation of DEM is the WorldView3 (WV3) launched by Digital Globe. The stereo imagery provided by this commercial satellite will be tested as a source data for topographic mapping and DEM formation. The main objective of this study is to evaluate height accuracy derived from this imagery as compared to classical total station ground survey.

WorldView-3 IMAGERY

WorldView-3 is a commercial Earth observation satellite owned by Digital Globe, bears a strong resemblance of WorldView-2 in terms of performance characteristics, in addition to significant improvements including cost savings and risk reduction. It was launched on 13 August 2014 to become Digital Globe's sixth satellite in orbit, joining IKONOS which was launched in 1999, Quick Bird in 2001, WorldView-1 (50cm resolution) in 2007, GeoEye-1 in 2008, and WorldView-2 in 2009. WorldView-3 provides commercially available panchromatic imagery of 0.31 m resolution, eight-band multispectral imagery with 1.24 m resolution, shortwave infrared (SWIR) imagery at 3.7 m resolution, and CAVIS (Clouds, Aerosols, Vapors, Ice, and Snow) data at 30 m resolution. It is capable of collecting about 1 billion km^2 of Earth imagery per year from an altitude of 617 km. The satellite has an average revisit time of <1 day with estimated service life from 10 to 12 years. Its swath width is 13.1 km at nadir. It has dynamic range of 11-bits per pixel Panchromatic and Multi Spectral (MS); 14-bits per pixel SWIR which can penetrate haze, fog, smog, dust and smoke. This spectral diversity enables various new imagery applications (Marchisio, 2014).

LITERATURE REVIEW

WV-3 super-high resolution imagery has been used in different applications, other than DEM formation which is the objective of this article. Some of these various applications including DEM formation that appeared in the literature are summarized below:

Johnson and Koperski (2017**)** have demonstrated through predictive statistical analysis carried out on the eight visible to near infrared (VNIR) bands (0.42 to 1.04 μm) and eight shortwave infrared (SWIR) bands (1.2 to 2.33 μm) of WV-3 imagery that a quick and accurate solution for mineral/geologic mapping can be provided. Fretwell, et al, 2017 carried out the first study utilizing 30-cm resolution imagery from the WorldView-3 (WV-3) satellite to count wildlife directly, at South Georgia. They found that satellite-based counts were comparable to ground-based counts with a slight over-estimation due to the presence of non-breeding birds. Parente and Pepe (2018) used the eight bands of the very high resolution commercial satellite (WV-3) imagery and Stumpf algorithm in order to obtain bathymetric data. They concluded that the use of optical satellite sensors can provide bathymetry data on large area in a short time and in a cheap way.

Mitchell, 2015 was able to demonstrate that WV-3 stereo satellite imagery can provide root mean square height accuracy of ± 15mm, using one control point for registration, in comparison with LiDAR (± 15cm accuracy) control.

Barazzetti et al, 2016 presented the orientation results for a single WV-3 image collected over Milan, Italy. The comparison with CPs from RTK GNSS, confirmed a similar geo-localization accuracy. In their paper, Hu, et al 2016 demonstrated that the geo-positioning accuracy of WV-3 stereo-images in a mountainous test area in comparison with the airborne LiDAR point cloud, the elevation biases of DEM extracted from the WV-3 stereo-pairs were about ± 0.62 m (std. value). This indicates that WV-3 imagery has the potential for 1:5000 scale mapping application. Rupnik, et al, 2018 tested formation of high quality digital surface models (DSM) from two high resolution satellite stereo imageries: Pleiades and WorldView-3 and revealed good performance in reconstructing non-textured areas, repetitive patterns and surface discontinuities. Loghin, et al, 2019 analyzed and assessed the geometric potential of DEMs generated from high-resolution Pléiades and WorldView-3 stereo and tri-stereo scenes for a hilly region in Allentsteig, Lower Austria. The test area was covered by arable lands and coniferous forests stretching from 300 m to 690m above MSL. Digital Surface Models (DSMs) and their absolute vertical accuracy were evaluated against a LiDAR-derived Digital Terrain Model (DTM). The results showed non-Gaussian distributions of errors, with a RMSE of ± 0.96 m (1.4 pixels) for Pléiades and of ± 0.37m (1.2 pixels) for WorldView-3. Mandanici, et al, 2019 tested height accuracy of stereo images of WV-3 over the city of Bolgona, Italy against check points and existing models of the area from LiDAR data and oblique aerial images. The test proved that roof surfaces and open spaces can be reconstructed with an average error of 1-2 pixels, but high discrepancies, reaching several meters was noticed in narrow roads and urban canyons. Domazetović, et al, 2020 evaluated vertical accuracy of WV-3 stereo imagery at two test sites within Olive Gardens of Lun Pag Island, Croatia. Obtained results (RMSE = ± 1.462m) demonstrated that WV-3 stereo imagery has great potential for application in creation of DSMs over large scale forested areas.

METHODOLY

TEST AREA

The selected test area is an open area within King Saud University (KSU) campus, which falls in the northern quarter of Riyadh city (geographical coordinates 24^o 38' North and 46^o 43' East), capital of Saudi Arabia.

Figure 1 shows the map of Saudi Arabia, surrounding countries and the location of the national capital Riyadh.

Fig. 1: Map of Saudi Arabia and its capital Riyadh [www-1].

KSU Campus, north of Riyadh City

Fig. 2: KSU Campus Boundary, north of Riyadh City [www-2].

Figure 2 shows the campus of KSU and surroundings. The topography of the area is not highly undulating varying between 640m and 652m above mean sea level.

Test Procedure

To assess WV-3 stereo image height accuracy for DEM formation, reliable GCPs and CPs were initiated using total station instrument. Two GCPs were used to tie the site area and a number of 267 CPs, as shown in figure 3 were well marked to be used in testing height accuracy.

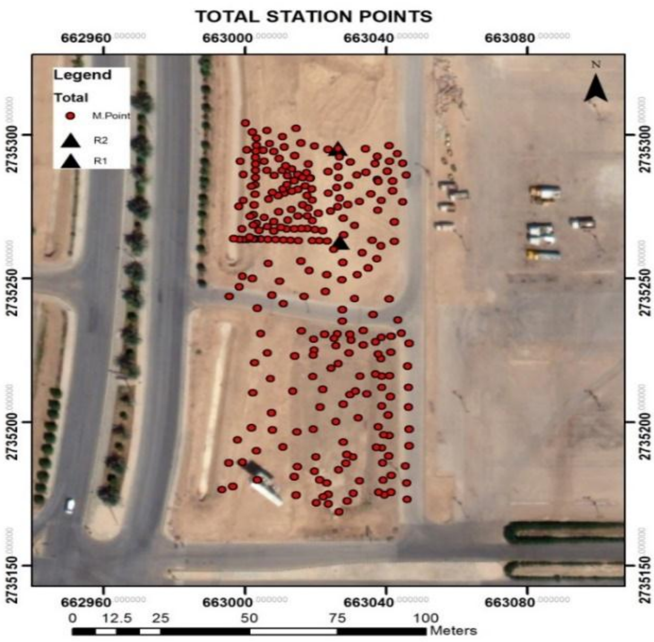

Fig. 3. Distribution of Control Δ and Test • Points.

Field work was carried out using TPS 1101 Leica total station to determine ground coordinates of all test points. The total station was first set up at one control point while the target was set up at the other control point for referencing and orientation. Then the measurements of coordinates of the CPs inside the test area were carried out and recorded.

Generation Of Dem From Wv-3 Stereo Imagery

Very High Resolution (VHR) optical satellites offer the most ever available overlapped area and Base to Height (B/H) ratio in satellite stereo images (Figure 4) which is really needed to produce high accuracy of image matching and thus in the resulting height accuracy for DEM formation.

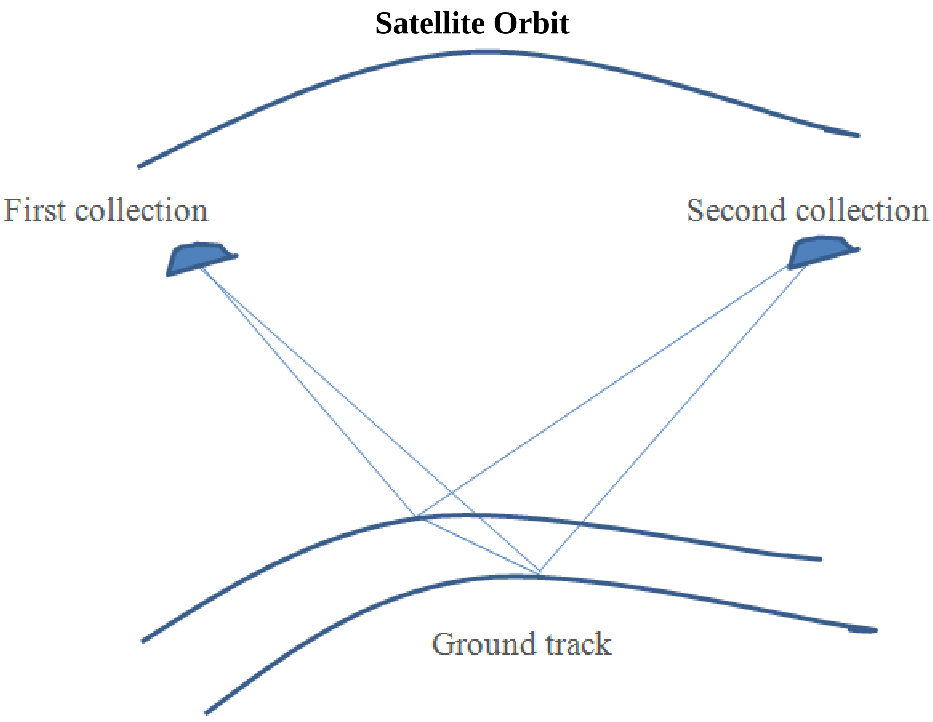

Fig. 4: Stereo Satellite Orbit Imagery.

In the World View series satellites there are primarily two situations for the along-track stereo area collection, i.e. multiple-view stereo and stitched stereo. The former acquires stereo-images of the same target area from at least triple view angles, while the latter aims at achieving a wide ground coverage by acquisition of several stitched stereo-pairs, alleviating the restriction in swath width of sensor due to the enhancement of spatial resolution (Hu, et al, 2016). Taking the situation of dual stereo-pairs for instance, the stereo area covering a size of 26.6 km by 112 km at maximum is available. The test area in this research is considerably small and not undulating. The workflow for DEM extraction from WV-3 stereo-images and accuracy evaluation is demonstrated in figure 5.

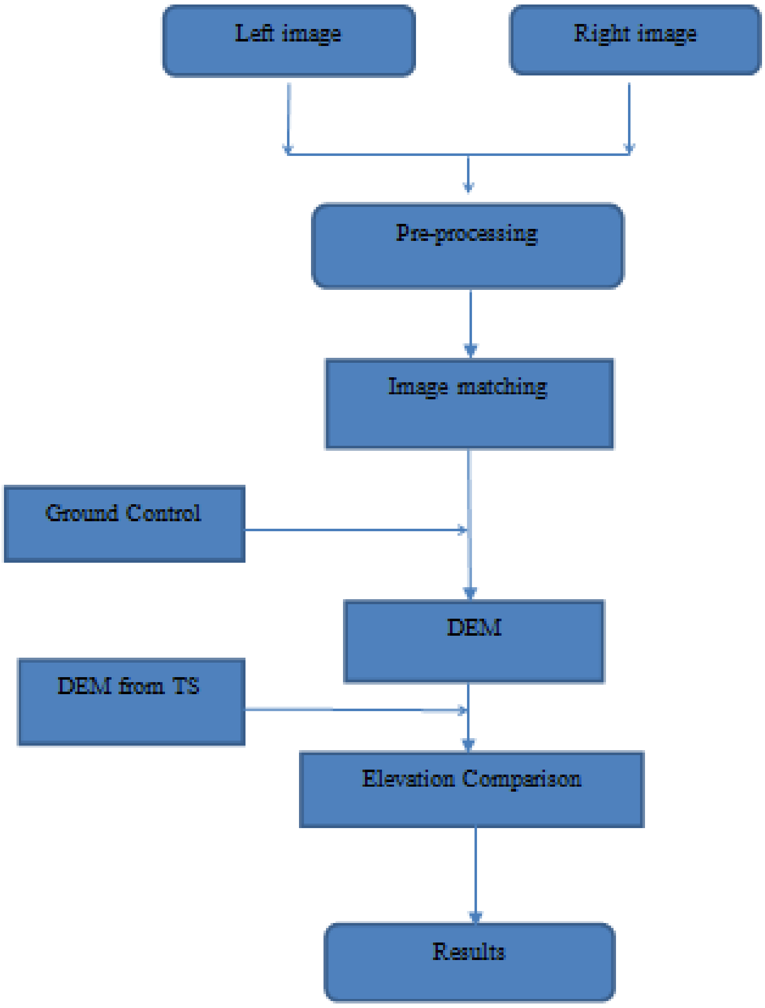

Fig. 5: Workflow for height accuracy testing.

The main steps of the test, shown on the workflow are explained as follows:

- Image point measurement of GCPs and tie points (TPs) for all test points. To generate high-accuracy DEM, GCPs these were measured semi automatically to high accuracy.
- Satellite images are subject to geometric distortions during acquisition. These distortions can be due to the acquisition system and the natural effects such as atmospheric refraction and earth topography (Brovelli et al, 2008). During pre-processing systematic image errors were removed using Rational Polynomial Functions (RPF) of known coefficients (Rational Polynomial Coefficients, RPC) provided by the company that manages the satellite using their proprietary rigorous models.

- Formation of stereo model can be created from quasi epi-polar images from the available stereo-pair after image error compensation, and carrying out density image matching, parallax and then elevation computing.
- Since the 3-D points automatically extracted by density image matching are all located on surface of the ground and targets, Digital Surface Model (DSM) instead of DEM is generated. To transform the DSM to DEM, particular manual editing and post-processing are needed for some regions within the model.
- Quantitative accuracy evaluation of DEM is done by comparing the WV-3 stereo-images derived DEM with the elevation of corresponding points already derived by TS observations.

RESULTS AND ANALYSIS

From statistical analysis minimum difference in elevation obtained using TS and WV-3 is 0.0m, while maximum difference is 8.8m with a mean of 4.3m and standard deviation of results from WV-3 imagery is ±1.7m as compared to TS derived elevations. Figure 6 shows histogram of differences in height obtained using WV-3 stereo imagery and total station ground survey approach.

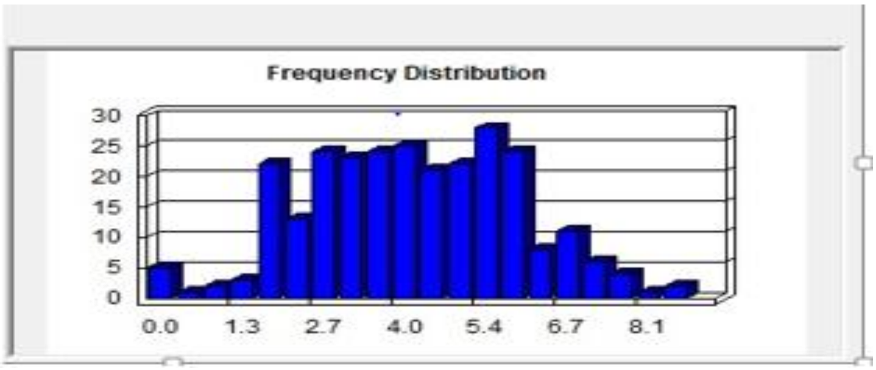

Fig. 6: Histogram of Elevation Differences between WV-3 and Total Station Results.

In previous studies, detailed in literature review of this article: Mitchell, 2015, Hu, et al, 2016, Loghin, et al, 2019, Mandanici, et al, 2019 and Domazetovic, et al, 2020 tested height accuracy of WV-3 stereo imagery when forming DEMs and in comparison with ground control points derived from LiDAR point cloud, root mean squares errors of obtained results were respectively ±0.15m, ±0.62m, ±0.37m, ±0.62m and ±1.46m. Results of test carried out in this study, using two ground control points for image registration, sits a little inferior to these results with the main difference that the test area in the current work is of a very small area having low height variation in comparison with other tests.

CONCLUSIONS

Test results in this study showed that the mean difference between ground point elevations produced by WV-3 satellite stereo imagery and that from total station is of standard deviation of ±1.71m. According to Linear Map Accuracy Standard (LMAS) this height accuracy is capable of producing topographic maps of scale 1:5000 and smaller (Petrovic et al, 2017). This same conclusion was derived by Hu et al, 2016.

Production of digital elevation models (DEM) from various stereo satellite sensors including WV-3 satellite sensor at 30cm resolution can be very useful for project planners, emergency operation managers, and logistics managers to plan field operations in a computer environment, ensuring that the best terrain conditions and access is provided to achieve project objectives.

A considerable improvement in the obtained elevation accuracy will allow data to be important for various DEM applications.

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