Photogrammetric 3D Modelling Potential Comparison of SFM-Based New Generation Image Matching Software

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ABSTRACT: Structure from motion (SFM) matching algorithm is the basic principle of new generation and widely used image matching software. Although these software work in common principle, their final products may contain different characteristics and distortions depending on their buried parameters. In the literature, there is lack of publishments which compare the three dimensional modelling performance of SFM based new generation software. Accordingly, our research group decided to carry out a study that could be a reference for upcoming researches. In this study, using VisualSFM, Agisoft and Pix4D SFM based image matching software, 3D digital surface models (DSM) were generated from unmanned air vehicle (UAV) high resolution aerial photos in a Campus of Zonguldak Bulent Ecevit University. Generated DSMs were comprehensively evaluated and compared by visual and statistical approaches utilizing the Agisoft DSM as the reference. The results clearly demonstrated the pros and cons of each analyzed SFM-based software.

KEYWORDS: SFM, VisualSFM, Agisoft, Pix4D, Digital Surface Model, Potential

1. Introduction

In recent years, rapid developing airborne remote sensing technologies such as airborne laser scanning (ALS) and unmanned air vehicle (UAV) became indispensable for land related engineering disciplines foremost mapping, city planning, forestry, mining and geology. The term “point cloud” entered our lives with ALS technology. Rapidly achievable and high resolution ALS point clouds enable the detailed vector description of surface objects with X, Y planimetric coordinates and altitude Z. By means of very successful applications with ALS point clouds, point cloud thought was adapted to photogrammetric image processing and aerial photos derived from UAV, were started to process with point clouds (Teizer et al. 2005; Rosnell and Honkavaara 2012).

In UAV technology, by the advantage of lower flight altitudes (≤300 m) against traditional photogrammetry and ALS (≥800 m), very high resolution (VHR) aerial photos are achieved. Moreover, by CMOS sensor-integrated multispectral digital cameras, the point clouds are provided with original colours (Rosnell and Honkavaara 2012; Swatantran et al. 2016). With the adaptation of point clouds to the UAV technology, several number of point cloud-based commercial software packages were released. These software packages support UAV stereo data processing for high resolution ortho-image and digital surface model (DSM) generation in target areas and the basic principle of them is “structure from motion (SFM)” matching algorithm. All of UAV users prefer one of the available software packages for data processing however they don’t know which software package is better for generating a better DSM.

In this study, we comprehensively analysed the coherence of Agisoft, Pix4d and Visual SFM (VSFM) which are the three of most preferred SFM-based image matching software packages. In the analysis, one of the main Campuses of Zonguldak Bulent Ecevit University was used as the study area which includes different land classes.

The paper was organized as follows: the study area is given in Section 2 and data processing methodology is presented in Section 3. The results are shown in section 4 followed by the conclusion.

2. Study area and Materials

The study area is the third biggest campus of Zonguldak Bulent Ecevit University, Turkey. It has different land classes as buildings, roads and vegetation. The big part of the topography is nearly flat and partially inclined at the southern part. Figure 1 shows the location of the study area and an instance aerial photo achieved in UAV flights. In UAV flights and terrain measurements, Zonguldak Bulent Ecevit University Civil Avation Academy’s DJI Phantom IV and SATLAB SL 600 GNSS receivers were used respectively. In Table 1, brief specifications of utilized UAV and GNSS receiver are given.

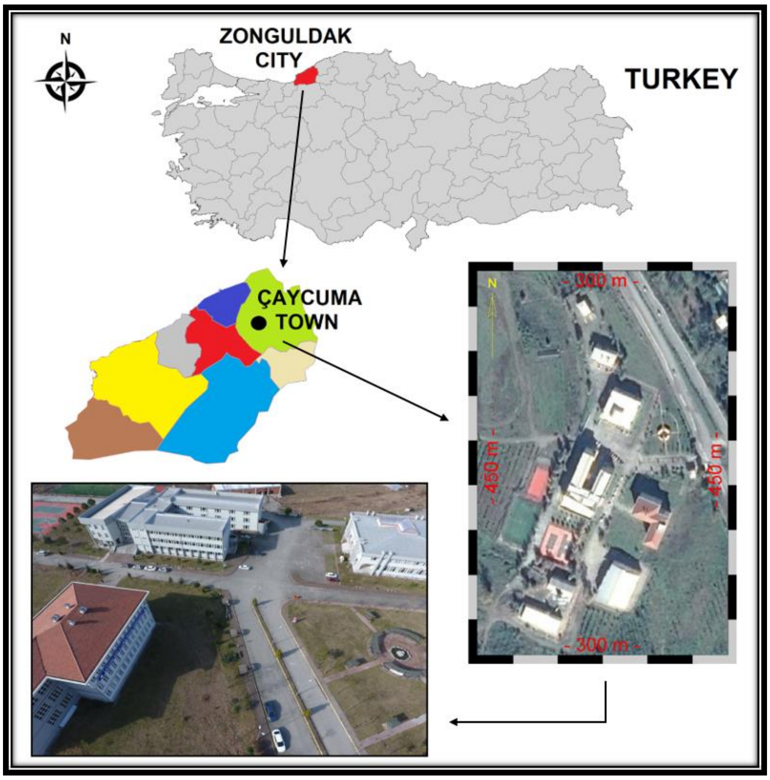

Figure 1. Location of the study area and an instance aerial photo achieved by the UAV flights

Table 1. Specifications of used materials

Specification	Value
DJI Phantom IV	
Camera	4K, HD, 1080p, 1/2.3", effective pixels 12.4M
Gimbal	3-axis (pitch, roll, yaw)
Flight duration	Max. 28 minutes
Weight	1380 gr
Speed	Max. 20 m/s
Wind speed resistance	Max 10 m/s
Operating temperature	0°- 40°
Outdoor positioning module	GPS + GLONASS dual
Positioning accuracy	0.1 m V, 0.3 m H (Vision); 0.5 m V, 1.5 m H (GPS)
SATLAB SL 600 GNSS	
GNSS technology	6G ; GPS, GLONASS, GALILEO, BeiDou, SBAS, QZSS
Operating system	Linux
Working modes	Static, VRS RTK, UHF RTK, all surveying modes
Internal Memory	1 GB
Positioning accuracy RTK	0.8 cm H, 1.5 cm V with 99.9% confidence level
Battery	Dual; 24 h static, 18 h RTK base, 15 h RTK rover
CORS-TR (Turkish GNSS system)	Available

3. Methodology

The methodology of the study was applied in two main parts as shown in Figure 2. Where the first part covers the processing steps from beginning up to DSM generation, the second part includes the visual and statistical coherence validation steps of the generated DSMs. In the first part, Agisoft, Pix4d and VSFM software packages were utilized for matching of aerial photos and generation of dense point clouds. In addition, Microstation TerraScan module was

2

utilized for examination and filtering of dense point clouds and LISA and Surfer software packages were used for DSM generation. In the second part, Bundle Block Adjusment Leibniz University of Hannover (BLUH) DSM validation software was utilized for shifting and comparison-based validation of generated DSMs. For visual interpretations and coherence map generation, LISA and Surfer software packages were also used in this part.

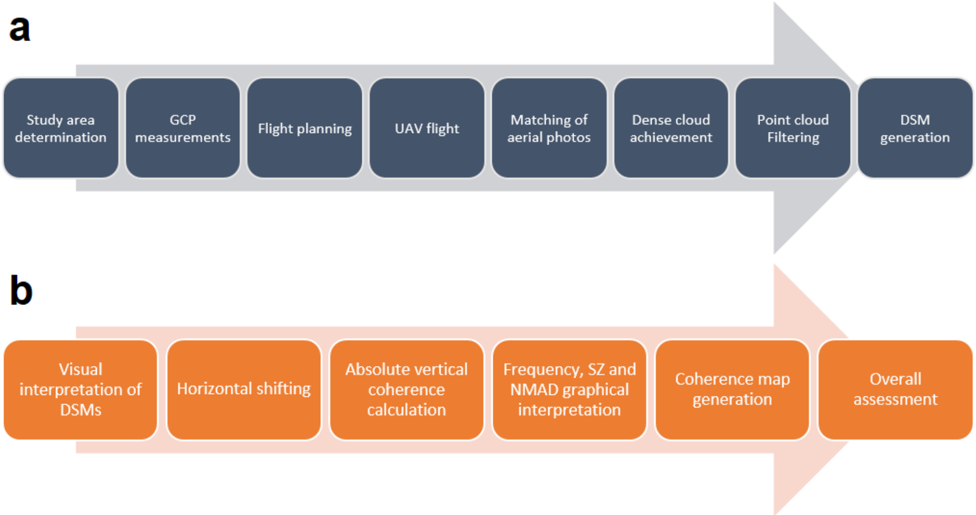

Figure 2. Methodology of the study; (a) generation steps, (b) validation steps

For correct matching of aerial photos taken by DJI Phantom IV UAV, 17 ground control points (GCPs) were established and measured on the terrain. The GCPs were measured by static GNSS method and have ≥ 1 cm horizontal and vertical positioning accuracy. The location of established GCPs and an instance GNSS measurement are shown in Figure 3.

Figure 3. The location of established GCPs and an instance GNSS measurement

In the flight planning, full coverage of the study area without any gap was the main target. Accordingly, entire area was achieved by minimum bundle (North-South, East-West) photos and the buildings were flown circular additionally. For testing the effect of more photos on the point cloud, half of the area was covered by bundle origin photos where the other half has repeated bundle obtained by shifting the flight strips. In the flights, minimum 80% lengthwise and 40% breadthwise overlap ratios and 5-10% oblique shooting were preferred. Figure 4 shows the used UAV on the terrain and the centres of achieved aerial photos.

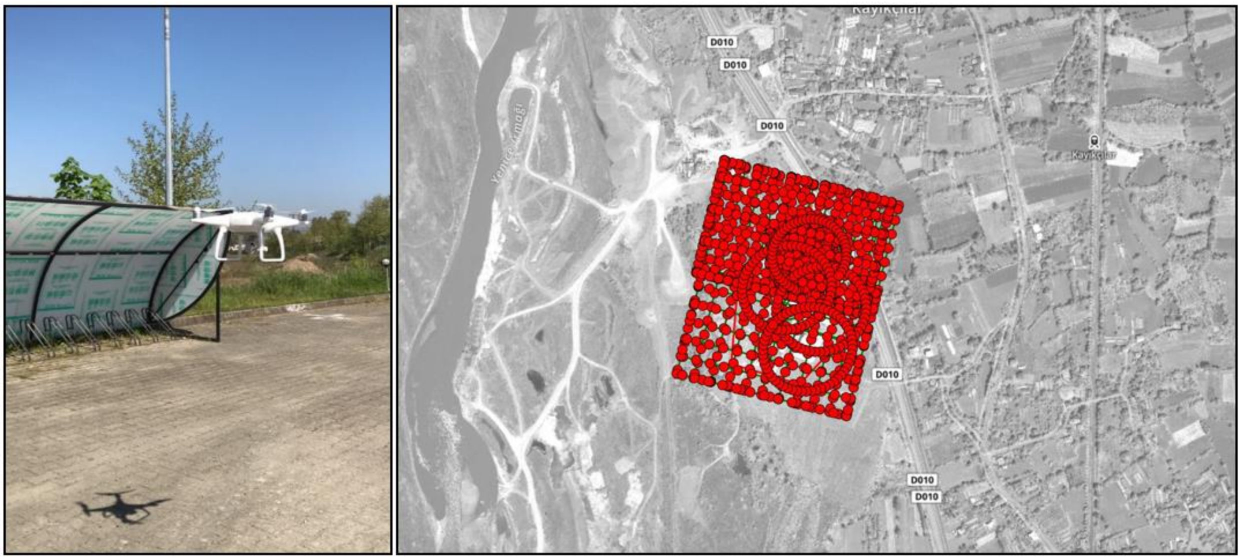

Figure 4. Used UAV and the flight plan

The achieved aerial photos were matched by Agisoft, Pix4d and VSFM software packages separately and high resolution point clouds were achieved. In Pix4d point cloud, noisy parts were available particularly at the South-Western part of the point cloud where the aerial photos were derived from one bundle flight (please check Figure 4). The detected noisy parts were filtered by determining a fence in the vertical profile of the point cloud. Figure 5 presents the noisy and filtered version of Pix4d point clouds. The DSMs of the study area were generated from Agisoft, Pix4d and VSFM point clouds separately. The original grid spacing was preferred as 0.25 m. For vector-raster transformation, data metrics interpolation method was chosen because of enabling the usage of maximum Z for each pixel. By interpreting the achieved point clouds and the DSMs, Agisoft DSM was preferred as the reference model for the study area and Pix4d and the VSFM DSMs were compared with it in validation analysis.

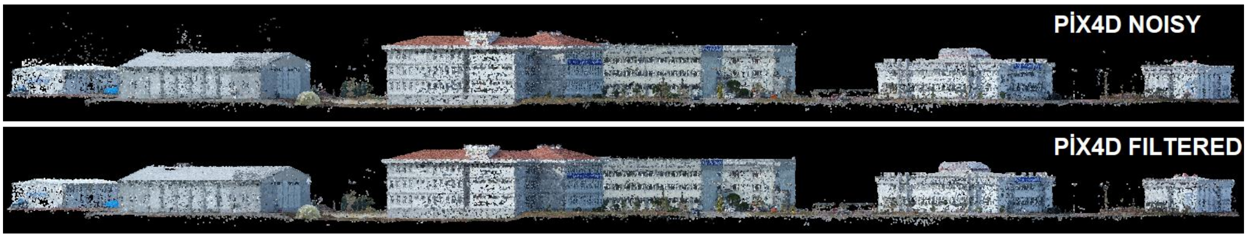

Figure 5. Noisy and filtered Pix4d point clouds

In validation of generated DSMs, some pre-corrections are indispensable. First, the coordinate system, horizontal datum and the vertical datum of the DSMs should be the same. Due to using same GCPs for the matching of UAV photos in Agisoft, Pix4d and VSFM, the coordinate system and the datum are the same. The common coordinate system is Universal Transverse Mercator (UTM), the horizontal datum is World Geodetic System established in 1984 (WGS84) and the vertical datum is orthometric. Another pre-correction is 100% horizontal overlap of compared DSMs which is the main rule of a correct vertical accuracy and coherence validation. The horizontal offsets between Agisoft, Pix4d and VSFM DSMs were eliminated by area based cross correlation (Baltsavias et al. 2008; Alobeid et al. 2010). Table 2 shows the estimated horizontal offsets based on standard deviation of differences in X and Y directions.

Table 2. Estimated and eliminated horizontal offsets

Reference DSM	**Compared DSM**	**ΔX (cm)**	**ΔY (cm)**
Agisoft (0.25m)	Pix4d (0.25m)	0.1	- 6.8
	VSFM (0.25m)	- 0.5	- 6.4

4

In vertical coherence analysis, standard deviation of pixel-based height discrepancies (SZ) was used (equation 1). In addition to SZ, the normalized median absolute deviation (NMAD) was used as the second coherence indicator. NMAD is a robust estimator particularly for major height differences however it is not as sensitive as SZ for the determination of minor outliers in a large data set (Hellerstein 2008). In the case of normally distributed height discrepancies between compared DSMs, NMAD is identical to SZ. If the NMAD is bigger than SZ this situation is an indicator for abnormal distribution of height differences. NMAD is the derivative of median absolute deviation (MAD), which is a robust measure of the variability of a univariate sample of quantitative data. MAD and NMAD are calculated by equations 2 and 3, where $\widetilde{X_J}$ is the median of the univariate data set of height discrepancies (ΔZ_1, ΔZ_2, ..., ΔZ_n) and $\widetilde{X_\iota}$ is the median of height discrepancies from $\widetilde{X_J}$. μ is the arithmetic mean of height differences between reference and compared DSMs. The coherence analysis was performed for inclined and uninclined areas separately using an inclination factor. In the analysis, slope < $\tan^{-1}$ 0.1 (~6°) was preferred as the threshold value for the separation of inclined areas.

$$\sigma_Z = \sqrt{\frac{\sum_{i=1}^{n}(\Delta Z_i - \mu)^2}{n-1}} \quad (1)$$

$$MAD = \widetilde{X}_i\left[\left|\Delta Z_i - \widetilde{X}_J(\Delta Z_j)\right|\right] \quad (2)$$

$$NMAD = 1.4826 \times (MAD) \quad (3)$$

The coherence maps between Agisoft and the compared DSMs were generated by equation 4.

$$Coherence\ map = DiffDSM = DSM_{AGISOFT} - DSM_{Compared} \quad (4)$$

4. Results

The points clouds achieved from Agisoft, Pix4d and VSFM are shown in Figure 6. As can be seen clearly, the Agisoft point cloud is closer to the real surface in comparison with the others. In Pix4d and VSFM point clouds, some remarkable gaps are available that means their matching performances are not as high as the Agisoft. Another finding is the number of achieved points after matching. Where Agisoft and Pix4d have similar number of points, VSFM generated one tenth of them with same number of aerial photos.

Figure 6. Agisoft, Pix4d and VSFM point clouds

The generated DSMs derived from Agisoft, Pix4d and VSFM point clouds are shown in Figure 7. In parallel with point cloud results, visual performance of Agisoft DSM is better than Pix4d and VSFM. Due to including lower number of points in DSM generation, the description potential of VSFM DSM looks faultier than the others. In comparison with Agisoft, both Pix4d and VSFM DSM have noise particularly at the area from one bundle flight (please check Figure 4). At the upper sides, the description potential of Pix4d and VSFM DSMs are higher than lower sides. That means, for higher 3D modelling performance in Pix4d and VSFM more aerial photos are needed in comparison with Agisoft.

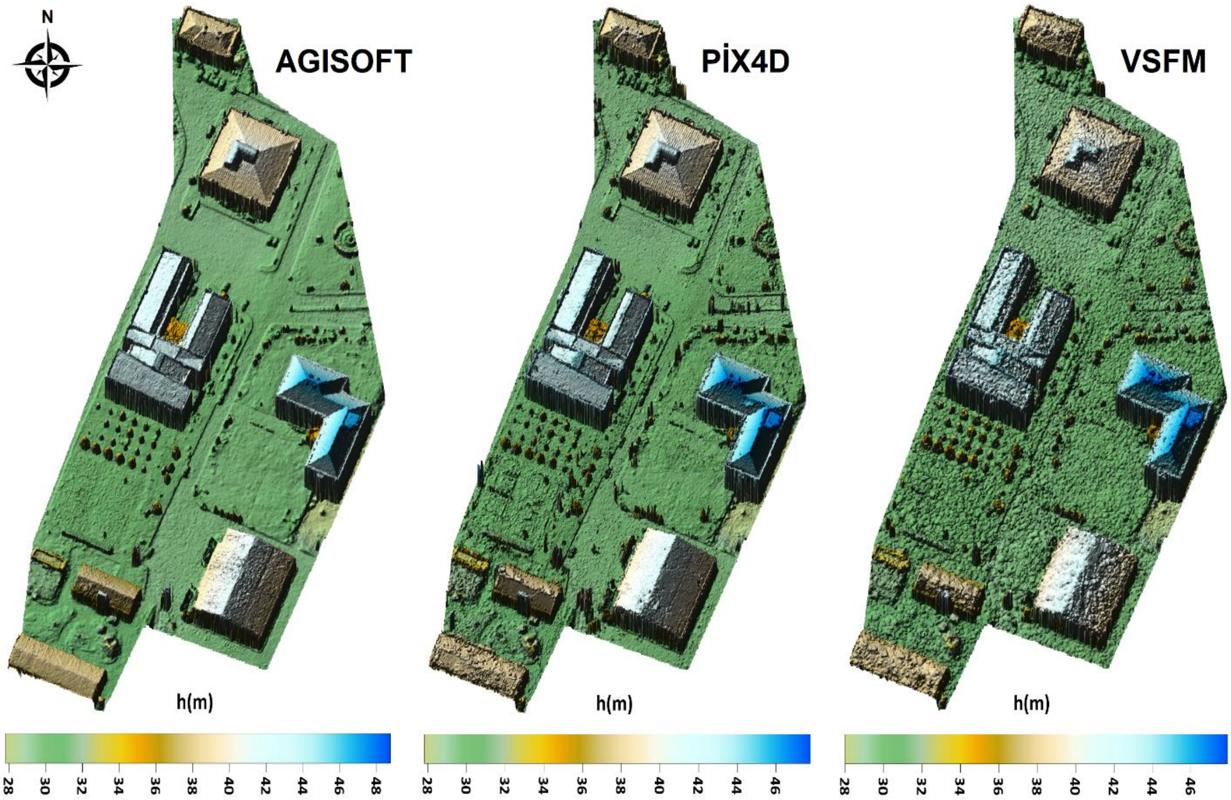

Figure 7. Generated DSMs derived from Agisoft, Pix4d and VSFM point clouds

In Table 3, absolute vertical coherence of Pix4d and VSFM DSMs with reference Agisoft DSM is given based on SZ and NMAD. In the Table, the results of whole and uninclined areas are shown separately. In the analysis, the pixels which have the height difference more than 1 m are excluded for correct interpretation. For Pix4d and VSFM, the percentage of excluded points are very similar and 0.91% and 0.89% respectively. In the analysis, systematic bias between the reference and the tested DSMs is calculated and eliminated by vertical shifting. According to the results, Pix4d and VSFM DSMs have similar absolute vertical coherence with Agisoft DSM. The NMAD results of both DSM are better than SZ which means the qualities are very close to Agisoft for general details however minor outliers, determined by SZ, have considerable influence on the absolute vertical coherence. Regarding the SZ results, approx. 0.4 m height difference exists for whole area. In uninclined areas (≤6°), the absolute vertical coherence is around 0.25 m for both DSMs.

Table 3. Absolute vertical coherence of Pix4d and VSFM DSMs with reference Agisoft DSM

Reference DSM	**Tested DSM**	**Class**	**Systematic bias (cm)**	**SZ (m)**	**NMAD (m)**	**Excluded points (%)**
Agisoft (0.25m)	Pix4d (0.25m)	Whole area	- 4.2	0.40 +0.12×tan(α)	0.12 +0.16×tan(α)	0.91
		Uninclined area		0.23	0.05	
	VSFM (0.25m)	Whole area	- 18.4	0.39 +0.11×tan(α)	0.15 +0.15×tan(α)	0.89
		Uninclined area		0.25	0.10	

6

Figure 8 shows the distribution of height differences between reference and tested DSMs based on frequency, SZ and NMAD. In Agisoft-Pix4d analyse, the NMAD has a better match with frequency against SZ and the peak of height differences is around zero which indicates a full coherence. However, at around 0.16 m, a second peak, which indicates an abnormal distribution, exists. This peak may be the influence of the area derived from one bundle flight. On the other hand, the structure of Agisoft-VSFM graph is totally different. The peaks of height differences are varied for frequency, SZ and NMAD. Where the peaks of SZ and NMAD are around zero, the frequency is around 0.06 m. The structures of the lines are more symmetric which indicates a normal distribution. However, the distribution scale is larger than Pix4d that signs lower absolute vertical coherence with the reference DSM.

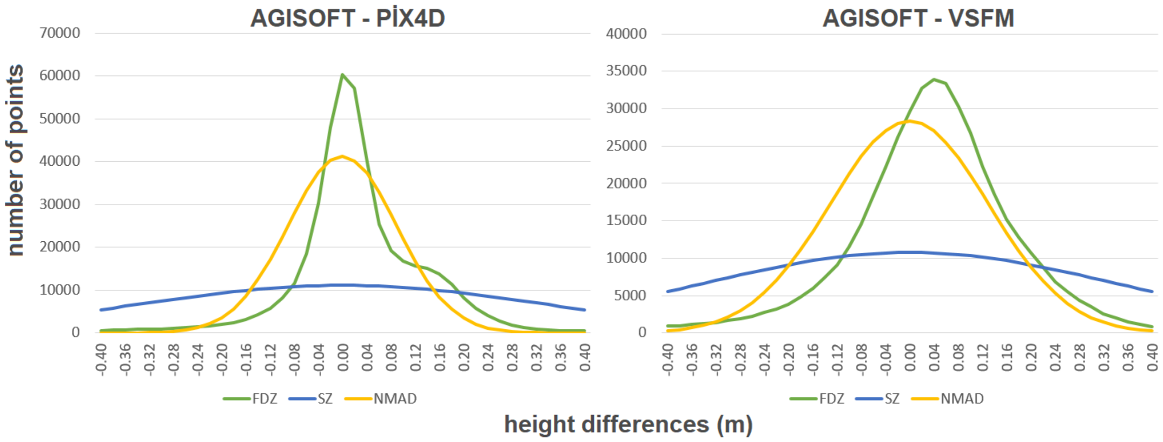

Figure 8. Distribution of height differences based on frequency, SZ and NMAD

Figure 9 shows the coherence maps of Pix4d and VSFM DSMs with reference Agisoft DSM with ±1 m height difference scale. The areas with orange colour represent nearly full coherent parts where dark blue signs the lowest coherence. The coherence maps demonstrate that Pix4d DSM is more coherent with reference Agisoft DSM. Particularly in building roofs and vegetated parts, the coherence of VSFM DSM is lower than Pix4d. For both DSM, the lowest coherence parts are the borders of the objects where the loss of accuracy by interpolation effect is maximum.

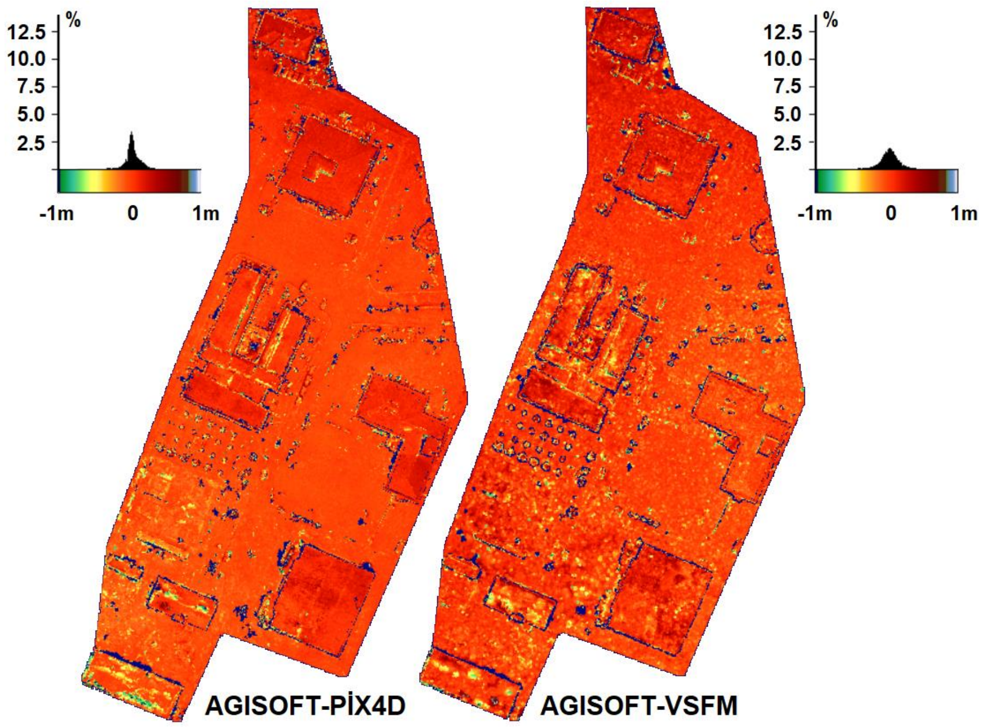

Figure 9. Coherence maps Pix4d and VSFM DSMs

7

Conclusions

In this study, the performance of new generation point cloud matching software packages Agisoft, Pix4d and VSFM was validated in detail. In a campus of Zonguldak Bulent Ecevit University, the 12 megapixel aerial photos were derived by DJI Phantom IV optical UAV and high resolution point clouds were achieved by investigated matching software packages. In Pix4d and VSFM point clouds, some remarkable gaps were reported. Where Agisoft and Pix4d have similar number of points, VSFM generated one tenth of them with same number of aerial photos.

Using the point clouds, 0.25 m gridded DSMs were generated and the Agisoft DSM was preferred as the reference for coherence validation analysis by representing the proximate real surface. Because of using lower number of points in DSM generation, the description potential of VSFM DSM looks faultier than the others. The absolute vertical coherence results demonstrated that Pix4d and VSFM DSMs have similar absolute vertical coherence with Agisoft DSM. The NMAD results of both DSM are better than SZ which means the qualities are very close to Agisoft for general details however minor outliers, determined by SZ, have considerable influence on the absolute vertical coherence. Regarding the SZ results, approx. 0.4 m height difference exists for whole area. In uninclined areas (≤6°), the absolute vertical coherence is around 0.25 m for both DSMs. In Agisoft-Pix4d analyse, the NMAD has a better match with frequency of height differences against SZ and the peak of height differences is around zero which indicates a full coherence. However, at around 0.16 m, a second peak, which indicates an abnormal distribution, exists. This peak may be the influence of the area derived from one bundle flight. In Agisoft-VSFM analyse, the peaks of SZ and NMAD are around zero, the frequency is around 0.06 m and the structures of the lines are more symmetric that indicates a normal distribution. The distribution scale is larger which signs lower absolute vertical coherence with the reference DSM.

The coherence map of Pix4d DSM is more coherent with reference DSM. Particularly in building roofs and vegetated parts, the coherence of VSFM DSM is lower than Pix4d. The lowest coherence parts are the borders of the objects where the loss of accuracy by interpolation effect is maximum.

Overall, visual and statistical results demonstrated that the DSM generated by Pix4d point clouds is more coherent with reference Agisoft DSM and the performance of VSFM DSM is lower than Pix4d and Agisoft.

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REFERENCES

Alobeid, A., Jacobsen, K., Heipke, C., 2010. Comparison of Matching Algorithms for DSM generation in urban areas from IKONOS imagery. Photogrammetric Engineering & Remote Sensing, 76(9):1041–1050.

Baltsavias, E., Gruen, A., Eisenbeiss, H., Zhang, L., Waser, T., 2008. High-quality image matching and automated generation of 3D tree models. International Journal of Remote Sensing 29(5):1243–1259.

Hellerstein, J. M., 2008. Quantitative Data Cleaning for Large Databases. Technical Report Presented at United Nations Economic Commission for Europe (UNECE), p. 42.

Rosnell, T., Honkavaara, E., 2012. Point cloud generation from aerial image data acquired by a quadrocopter type micro unmanned aerial vehicle and a digital still camera. Sensors 12:453–480.

Swatantran, A., Tang, H., Barrett, T., 2016. Rapid, high-resolution forest structure and terrain mapping over large areas using single photon lidar. Sci Rep 6:1–12.

Teizer, J., Kim, C., Bosché, F., 2005. Real-time 3D Modelling for Accelerated and Safer Construction using Emerging Technology. 539–543