Journal of Al-Azhar University Engineering Sector

Vol.19, No. 70, January 2024, 67- 79

# LANDSCAPE MODELING FROM AERIAL IMAGERY DIGITAL SURFACE MODELS GENERATED WITH THE USE OF THE DENSE MATCHING ALGORITHM

**Fahmy F. F. Asal***

Civil Engineering Department, Faculty of Engineering, Menoufia University, Egypt.
***Correspondence:** fahmy.asal@sh-eng.menofia.edu.eg

**Citation:**

F. F., F, Asal. "Landscape Modeling from Aerial Imagery Digital Surface Models Generated with the Use of Dense Matching Algorithm", Journal of Al-Azhar University Engineering Sector, vol. 19, pp. 67 - 79, 2024.

**Received: 16 November 2023**

**Revised: 6 January 2024**

**Accepted: 17 January 2024**

**DOI: 10.21608/auej.2024.249111.1474**



## ABSTRACT

DSM generation through exploitation of different digital image matching techniques has been a hot research area for the last two decades where different image matching algorithms have been developed and become available under different image processing software. This motivated to increasing in researches for investigation of the qualities of those DSMs. However, many questions regarding the qualities of the image matching DSMs and their capabilities in representing different types of landscapes have not yet been completely answered. This research aimed at undertaking qualitative and quantitative investigations of the DSMs generated from aerial imagery stereo pairs with the use of the dense matching algorithm in addition to examining the efficiency of those DSMs in modelling of rural landscapes. Aerial imagery DSMs generated with the use of dense matching algorithm at two different resolutions for Vaihingen, Germany have been used in the study. Visual analysis shows clear representation of features in both DSMs of 0.09 and 0.14315 meter ground resolutions. However, the differences between the two DSMs are hardly noticeable visually. On the other hand, statistical analysis shows higher standard deviation of the DSM of 0.09 meters compared to that of the DSM of 0.14315 meter ground resolution which refers to better detailing of the rural landscape in the DSM of 0.09 meter ground resolution. Also, a standard deviation of the residual DSM of about 0.15 meters has been obtained. Additionally, the accuracy analysis with external ground truth checkout points shows that the residuals of the elevations extracted from 0.09 meter DSM are more accurate than those extracted from the 0.14315 meter DSM. Moreover, feature extraction from both DSMs shows that fine geometrical shapes of the multiple bay business building have been extracted, however, editing for removal of spikes from the raw DSMs could lead to extraction of better geometrical shapes that could be close to the real world. Finally, it can be recommended that the dense matching algorithm works well at ground elevation features such as roads compared to its performance at buildings and complicated structures.

**KEYWORDS**: Airborne digital imaging, Automated generation DSM, Accuracy assessment, Feature extraction, Visual analysis.

# نمذجة المعالم الأرضية من نماذج الأسطح الرقمية التي يتم إنشاؤها باستخدام خوارزمية المطابقة الكثيفة للصور

**فهمي فهيم عسل***

قسم الهندسة المدنية، كلية الهندسة بشبين الكوم، جامعة المنوفية، مصر.
*البريد الاليكتروني للباحث الرئيسي : fahmy.asal@sh-eng.menofia.edu.eg

## الملخص

لقد كان إنشاء نماذج الأسطح الرقمية (DSMs) من خلال استغلال تقنيات مطابقة الصور الرقمية المختلفة مجالًا بحثيًا ساخنًا على مدار العقدين الماضيين حيث تم تطوير خوارزميات مختلفة لمطابقة الصور وأصبحت متاحة وتعمل تحت برامج معالجة الصور المختلفة. وهذا ما حفز على زيادة الأبحاث لدراسة مدى جودة ودقة تلك النماذج، ومع ذلك، فإن العديد من الأسئلة المتعلقة بجودة DSM المنشأة من مطابقة الصور الرقمية ومدئ قدراتها علئ تمثيل مختلف أنواع المعالم الأرضية لم تتم الإجابة عليها بشكل كامل بعد. يهدف هذا البحث إلى إجراء دراسة نوعية وكمية لنماذج DSM المنشأة من أزواج الصور الجوية المجسمة باستخدام خوارزمية المطابقة الكثيفة للصور الرقمية بالإضافة إلى فحص كفاءة نماذج DSM في نمذجة المعالم الأرضية في المناطق الريفية.حيث تم استخدام نماذج DSM منشأة من الصور الجوية الرقمية والتي تم إنشاؤ ها باستخدام خوارزمية المطابقة الكثيفة بدقات مختلفة لمدينة فايهينجن بألمانيا في الدراسة.كما تم الحصول على تمثيل واضح للمعالم الأرضية في كلا DSMs ذي الدقة الأرضية 0.09 و0.14315 مترا. ومع ذلك، فإن الاختلافات بين نموذجي DSMs بالكاد تكون ملحوظة بصريًا. من ناحية أخرى، يُظهر التحليل الإحصائي انحرافًا معياريًا أعلى لـ DSM بدقة أرضية 0.09 مترًا مقارنةً بالانحراف المعياري لـ DSM بدقة أرضية 0.14315 مترًا والذي يشير إلى إعطاء تفاصيل أفضل للمعالم الأرضية في المناطق الريفية في DSM بدقة أرضية 0.09 مترًا. أيضا تم الحصول على انحراف معياري لـ DSM الفروق بحوالي 0.15 متر. بالإضافة إلى ذلك، فإن تحليل الدقة باستخدام نقاط التحقق الأرضية الخارجية يوضح أن فروق الارتفاعات المستخرجة من DSM بدقة أرضية 0.09 مترًا هي أكثر دقة من تلك المستخرجة من DSM بدقة أرضية 0.14315 مترًا. علاوة على ذلك، يُظهر استخراج المعالم الأرضية من كلا نموذجي DSM أنه تم استخراج أشكال الهندسية جيدة لمبنى الأعمال المتعدد الباكيات، ومع ذلك، فإن عمل التصحيحات لإزالة الأغلاط من نماذج DSM الخام يمكن أن يؤدي إلى استخراج أفضل للأشكال الهندسية والذي يمكن أن يكون قريبا إلى الطبيعة. وأخيرا، يمكن التوصية بأن خوارزمية المطابقة الكثيفة تعمل بشكل جيد في تمثيل المعالم المستوية ذات المناسيب الأرضية مثل الطرق مقارنة بأدائها في تمثيل المباني والهياكل المعقدة.


**الكلمات المفتاحية :** التصوير الجوي الرقمي، نماذج الأسطح الرقمية من الطرق الألية، حساب الدقة، استخراج المعالم الأرضية، التحليل المرئي.

# 1. INTRODUCTION

There is a growing demand for recent and accurate geo-information for modeling different types of landscapes. This has given more interest in the digital surface models that encompasses high level of details [1]. Landscape modelling and feature extraction from airborne imagery stereopairs with exploitation of automated image matching methods has been a hot research topic for the last two decades. Mostly research projects dealing with feature extraction focused on individual object classes such as buildings, roads, and trees [2, 3]. Usually, the available data sets would be outdated because they have been based on scanned aerial photos exposed with analog cameras from long times. Nowadays, with the availability of digital aerial cameras, new standard test sites for feature extraction research have been available [4]. So, there is a need to uncover the capabilities and potential of the recent technologies for airborne imaging data regarding multiple-overlap geometry, increased radiometric and spectral resolution [5, 6].

Digital Surface Model (DSM) has been a standard product of airborne imaging systems through application of the digital image matching techniques on digital imagery stereo pairs [7]. Also, DSM can be extracted from stereo imageries obtained from space-based platforms and can be exploited in different applications demanding different levels of accuracy requirements [7, 8]. For example, DSM constitutes an important and crucial input in natural resources investigation, urban management and monitoring, forestry, analysis of geological disasters, etc. This makes the application of accuracy investigation on the DSMs produced from image matching techniques necessary. In this context, there are different factors that control the quality of the digital image matching DSMs including: the radiometric and geometric quality of the original imagery stereo pair, the efficiency of the sensor model that controls the relationship between the image space and the object space and finally, the performance of the digital image matching algorithm [9]. Thus, the errors that arise in the image matching DSM might be due to insufficient texture in the original images, occlusions, or radiometric artifacts where these factors could increase inaccuracies in the created DSM from the image matching methods [10]. For these reasons, the accuracy of a DSM generated from aerial and satellite imagery stereo pairs can be assessed with the use of accurate Light Detection and Ranging (LiDAR) measurements that can be considered as ground truth data if available [1].

## 2. DIGITAL IMAGE MATCHING

DSM is an important product that describes the Earth's surface that is necessary for many applications such mapping, navigation, military applications, and smart city planning [9, 11]. With the continuous improvement of optical remote sensing image resolution, DSM with meter and even sub-meter resolution generated by stereo matching has become attainable [12, 13]. Stereo matching, for obtaining elevation from digital image stereo pairs has been hotspot research for decades in digital photogrammetry and computer vision where some stereo matching algorithms has become capable of producing DSMs of elevation accuracy that can be as close as to the accuracy given by LiDAR in elevation estimation. On the other hand, poor texture in the overlapped digital images still constitutes big challenges for image matching where DSMs automatically extracted in poor texture areas definitely requires great amount of manual editing before being exploited in different applications [9]. Automatic DSM generation through application of digital image matching can be extracted from aerial surveying systems and techniques or from optical satellites systems through the application of reliable digital image matching approaches [7, 14]. Various image matching algorithms have been developed based on area-based image matching, feature-based image matching, and symbolic-based image matching have become commercially available. As stated before, there are different factors that affect the quality of the resulting DSMs from the application of different image matching approaches on digital image stereo models. In addition to the forementioned factors, the digital image resolution, differences in the digital image sun-angle in addition to the digital image viewing geometry have significant and direct effects on the generated DSM [8, 15]. Also, different Image matching methods encounter similar problems in DSM generation such as bad texture in one or more of the overlapped digital images, object discontinuities, objects with no flat surface, repetitive objects, occlusions, moving objects including shadows of the different objects, multi-layered and transparent objects, radiometric artefacts like specular reflections, etc. [11]. The preciously mentioned factors may be eliminated or reduced through performing aerial surveys in a proper time of the day and during fine weather conditions [15]. Balenović et al., 2015 [15], present a workflow for extraction of high-density DSM through exploitation of area-based image matching approach on Color Infra-Red (CIR) digital stereo aerial images. Also, they evaluated the quality of the generated comparison with manual stereo measurements over three different land cover classes: forests, shrubs, and grasslands. They recommend good vertical agreement has been achieved between the image matching DSM and manual stereo measurement for all the examined three land cover classes.

Dibs and Al-Ansari, 2023 carried out a study that involves integrating remote sensing, Geographic Information Systems (GIS), and architecture environment software environments for creation of detailed three-dimensional model following some steps that include having high-resolution satellite imagery; getting ground truth data, removal of image noise, generation of two-dimensional model to create a DSM in GIS using extracted features outlines, convert the model into multi-patch layers to construct 3D mode [1]. They recommended that the 3D model obtained through their method was highly detailed and useful for various applications [1]. Also, Kuschka et al., 2014 state that the Working Group 4 of Commission I of the International Society for Photogrammetry and Remote Sensing (ISPRS) is concerned with geometric and radiometric modeling of optical airborne and spaceborne sensors and has provided benchmark dataset assessment of the accuracy of dense stereo image matching algorithms. This has been for the purpose of improvement of the quality of the image matching algorithms for automatic generation of DSMs from optical stereo imageries. They acknowledged that the provided data consisted of several optical spaceborne stereo images together with ground truth data produced by aerial laser scanning [16].

Mahphood, et al. 2019 stated that DSM can be extracted from stereo pairs of satellite or aerial images where the Semi-Global Matching (SGM) algorithm has been exploited in extraction of DSMs from overlapped satellite and aerial images stereo pairs. They presented an approach for improvement of the accuracy of DSM created from multi-view satellite stereo imageries with the use of SGM algorithm using several filters [17]. These filters ware designed to delete mismatches between very tall buildings in urban areas and remove sea areas where they implemented the approach on five sequential high-resolution images acquired by the Worldview-2 satellite. They acknowledged that such method could achieve below half-pixel accuracy DSM which can be useful for different applications such as urban planning, flood control, resource management, telecommunication planning, military mapping, ...etc. Additionally, Yang et al., 2020 state that digital image matching methods are widely used for DSM generation due to their accuracy and efficiency except for water areas due to poor texture in those areas. That’s why a large amount of manual editing is necessary for DSMs extracted in water areas. Moreover, Yang et al., 2020 present a paper that proposes DSM generation method, named Semi-Global and Block Matching (SGBM), for height estimation in water areas with the use of adaptive block matching instead of pixel matching. They recommend that the DSM generated by such method in water areas has achieved high accuracy with better visual quality [9].

Hobi and Ginzler, 2012 state that DSMs are widely used in forestry for modeling the forest canopy [18]. They present research aimed at assessment of the accuracy of DSMs generated with the application of digital image matching on a WorldView-2 satellite imagery stereo pair and DSMs extracted from Leica ADS80 digital aerial imagery stereo pairs using Rational Polynomial Coefficients (RPCs) for production of a digital image matching DSM. Then, they used the same polynomial enhanced with Ground Control Points (GCPs) to get another DSM. They acknowledge that Very High-Resolution Satellite Imageries (VHRSI) have a submeter ground resolution, so, they can offer potential and efficient alternatives to airborne survey digital imageries for DSM generation with the use of digital image matching methods. However, the accuracy of the DSM generated from digital image matching of overlapping digital imagery stereopairs depends on a number of variables including the surface roughness of the terrain, the interpolation function, the interpolation methods in addition to the three attributes namely; the accuracy, density, and distribution of the source data [18].

This research aimed at examining the efficiency of the DSMs extracted from aerial imagery stereo pairs with the use of automated methods basing on dense matching algorithm in modelling of rural landscapes. Additionally, application of qualitative and quantitative assessments of the DSMs generated from aerial imagery stereo pairs with the use of the dense matching algorithm at varying ground resolutions constitutes a main objective of the research. Finally, feature extraction and analysis of some landscape elements from the DSMs created with exploitation of the dense matching algorithm is an important objective of the study.

## 3. TEST SITE, DATASET AND METHODOLOGY

Figure 1 is an ortho image for the test site where the test data used in this study is a clipped DSM from the whole DSM that was created from aerial imagery stereo pairs with the use of automated methods for Vaihingen in Germany. Such data set is a subset of the data exploited for testing of digital aerial cameras and undertaken by the German Association of Photogrammetry and Remote Sensing (DGPF) [19]. The original DSM has been extracted from original aerial imagery stereo pairs with the use of dense matching model under the Match-T DSM software [20]. The extracted DSM was employed in generating orthophoto mosaic at ground grid resolution of 9.0 cm. Also, the test site area was covered by 10 strips of airborne laser scanning data captured with a Leica ALS50 system at an average point density of 4 pts/m$^2$ [21].

**Fig. 1.** An ortho image extracted from aerial imagery stereo pairs at rural landscape.

The test area is located at the west bank of a river at Vaihingen city, Germany, and has variety of rural landscape elements including water areas constituting a river that appears in black in the false color orthophoto, see figure1. It also contains wide park areas in red in addition to some rows of trees. Also, wide paved park areas in gray can be interpreted. Additionally, some multi bay business buildings can be interpreted along with some detached buildings. A DSM of 9cm ground resolution and another DSM of 14.315cm ground resolution covering the test area have been clipped from the whole DSMs covering the whole Vaihingen city for evaluation of the efficiency of the image matching DSMs in modelling of rural landscapes. In this study visual analysis along with statistical analysis of the provided DSMs at two different ground resolutions have been undertaken. Additionally a difference DSM for the test area has been produced to assess the effect of the ground resolution as an image matching parameter on the quality of the created DSM. Moreover, the accuracy of the examined DSMs has been assessed with use of external checkout point extracted from the provided Airborne Laser Scanning (ALS) point clouds. Finally, feature extraction for two different elements of the rural landscapes has been carried out and evaluated. Different analysis software including LAStools, ESRI ArcView 3.3, SAGA 9.1.3, Surfer 10 and Excel has been exploited in the different types of analysis fulfilled by this study.

# 4. RESULTS AND DISCUSSIONS

## 4.1. Visual Analysis of Aerial Imagery DSMs

Figures 2 and 3 are two DSMs created at two different ground resolutions of 0.09 meters and 0.14315 meters respectively in an area of rural landscape and located at the west bank of Vaihingen city river. The two DSMs were created and provided by the German Society for Photogrammetry, Remote Sensing and Geoinformation (DGPF) from aerial imagery stereo pairs with the use of dense matching model under the Match-T DSM software (Lemaire, 2008). Visual analysis of the two DSMs shows clear representation of features in both DSMs of 0.09 and 0.14315 meter ground resolutions. However, the differences between the two DSMs are hardly noticeable visually. This is clear in the similar tones and similar textures in both DSMs which can be interpreted as both resolutions of 0.09 meter grid cell size and 0.14315 meter grid resolutions can be considered as fine and close resolutions especially, when dealing with ground features of multiples of meters in dimensions and sizes. Also, similar color patches in shapes, sizes and distributions are interpretable in the two DSMs of different ground resolution. Also, with regard to the patterns which refer to the arrangements of the objects in the corresponding DSMs it can be seen that similar patterns have been obtained in the two different resolution DSMs. Finally, when comparing with ortho image in figure 1 it can be said that both DSMs created from aerial imagery stereo pairs with the use of dense matching algorithm depict fine representation of the different element rural landscape elements.

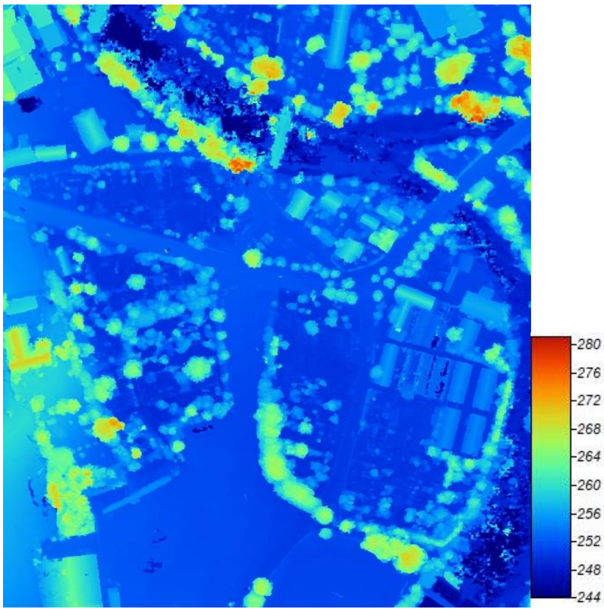


**Fig. 2:** DSM extracted with the use of automated methods at a spatial resolution of 0.09 meters in rural landscape.

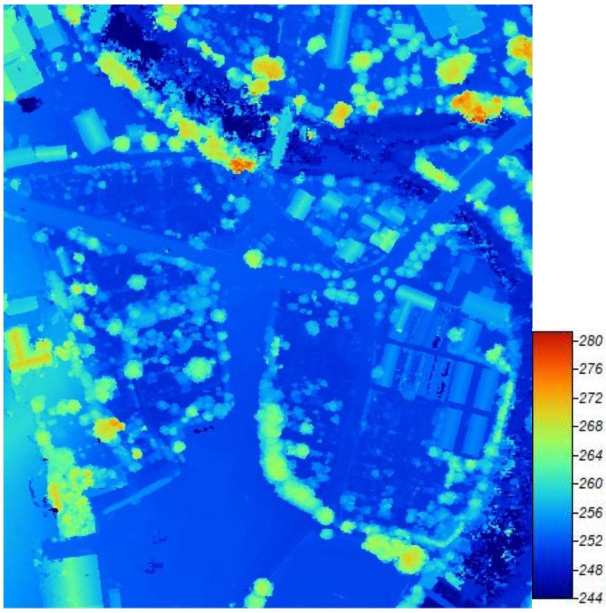


**Fig. 3:** DSM extracted with the use of automated methods at a spatial resolution of 0.14315 meters in rural landscape.

## 4.2. Statistical Analysis of Image Matching DSMs

Table 1 depicts the statistical analysis results of the DSMs extracted at two different resolutions from overlapped aerial Imagery stereo pairs with the use of digital image matching methods in rural landscapes. From table 1 it can be noticed that the number of the data cells in the DSM of the 0.09 meters resolution is large compared to the that in the DSM of 0.14315 meters of ground resolution (more than 2.5 times). This refers to how the grid cell size determines the size of the DSM file and consequently the required computing system capabilities for processing and storage requirements. Also, it seems that the DSM of 0.09-meter ground resolution enjoyed better extraction strategy parameters leading to zero no data cells while some no data cells are included in the DSM of 0.14315-meter ground resolution. The other corresponding statistical quantities including the maximum elevations and minimum elevations are not far from each others in both DSMs with wider range of elevations and higher standard deviation of elevations in the DSM of 0.09 meters. This can be due to the effect of elevation smoothing in the DSM of 0.14315 meters ground resolution. Finally, the sum of elevations contained in the DSM of 0.09 meters ground resolution is higher than that in the DSM of 0.14315 meters ground resolution due to the bigger number of cells in the DSM of 0.09 meters of ground resolution.

**Table 1:** Statistical analysis of the DSMs extracted at two different resolutions from overlapped aerial imageries with use of a digital image matching technique in rural landscapes.

| Statistical Quantity | DSM_09cm | DSM_14cm |
|---|---|---|
| DSM data cells | 17291050 | 6834454 |
| DSM no data cells | 0 | 4562 |
| DSM cell size (meters) | 0.09 | 0.14315 |
| Mean elevation (meters) | 253.6649 | 253.6728 |
| Min, elevation (meters) | 215.7259 | 216.662 |
| Max. elevation (meters) | 280.8144 | 281.1406 |
| Range elevation (meters) | 65.08849 | 64.47859 |
| Sum of elevation (meters) | 4.39E+09 | 1.73E+09 |
| Variance of elevation ($m^2$) | 23.11229 | 23.0543 |
| Standard deviation of elevations (meters) | 4.807524 | 4.801489 |
| Standard deviation of the mean elevation (meters) | 0.001156 | 0.001836 |

## 4.3. Generation and Analysis of Residual DSM

Figure 4 depicts a residual DSM calculated as the algebraic difference between the DSM of 0.09 meters and that of 0.14315-meter ground resolution after being resampled to a DSM of 0.09 meters for the purpose of unifying the number of the cells in both DSMs and making the subtraction operation applicable. From figure 4, the main differences between the two different resolution DSMs occur at the edges of the objects of different types including trees, buildings, bridges, ...etc. Also, at gradually varied or flat areas the residual elevations tend to be of zero value. This can be interpretable from table 2 which depicts the statistical analysis results of the residual DSM where the mean elevation tends to be of zero value (0.00155 meters). Additionally, from table 2 a wide range of elevation differences between the two different resolution DSMs has been obtained that can be due to spikes that usually arise during the automatic extraction process of the DSMs. For this reason, creation of DSMs with fully automated methods requires editing operations for removal of such spikes that definitely could affect the statistical analysis results of the DSM. Also, a standard deviation of elevation residuals of about 0.15 meters has been obtained that has to be expected as degradation of elevation accuracy usually occurs when there is degradation in the DSM ground resolution.

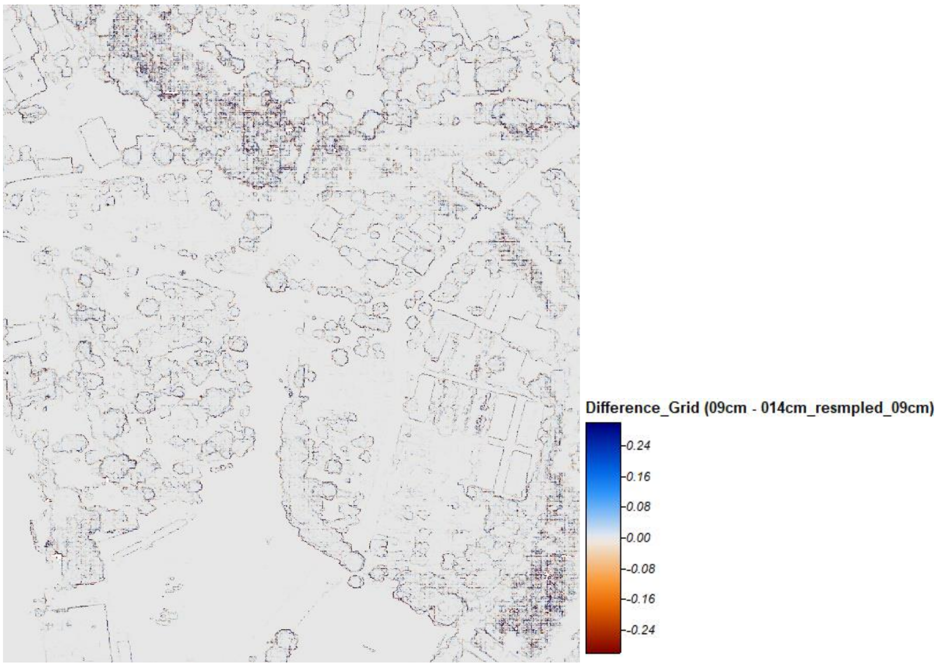


**Fig. 4:** Residual DSM created as the algebraic difference between the DSM of 0.09 meters and the resampled DSM of 0.14315-meter ground resolution in rural landscape.

**Table 2:** Statistical analysis of the residual DSM created as the algebraic difference between the DSM of 0.09 meters resolution and the DSM of 0.14315-meter resolution resampled at 0.09 meters in rural landscape.

| Statistical Quantity | Residual DSM (DSM_09cm – resampled DSM_14cm) |
|---|---|
| Data Cells | 17279672 |
| No data Cells | 11378 |
| Cell size (meters) | 0.09 |
| Mean Residual (meters) | 0.00155 |
| Min. Residual (meters) | -37.285 |
| Max. Residual (meters) | 3.28174 |
| Range of Residuals (meters) | 40.5669 |
| Sum of Residuals (meters) | -26727.8 |
| Variance of Residuals ($m^2$) | 0.022622 |
| Standard Deviation of Residuals (meters) | 0.150405 |

## 4.4. Accuracy Estimation of Image Matching DSMs of Different Resolutions

This analysis concerns with assessment of the accuracy of the measured elevations from the DSM generated from overlapped aerial imagery stereo pairs with the use of automated methods basing of image matching algorithms at two different spatial resolutions of 0.09 meters and 0.14315 meters respectively. The philosophy of this test is based on measuring point elevations from the DSMs at every position of some externally and precisely measured elevation checkout points. In this analysis the elevations of the external checkout points are considered as ground truth data where the extracted elevations from the DSMs can be compared with them to get the residual elevations as the difference between the elevations of the external checkout points and the DSM elevations at the same corresponding positions of the checkout points. In this case a similar number of elevation residual to the number of the checkout points can be obtained and statistically analyzed. In the study, a number of 325 external checkout points extracted from airborne laser scanning point clouds, accompanied with the test data sets provided by German Society for Photogrammetry, Remote Sensing and Geoinformation (DGPF) have been randomly extracted with the use of SAGA software to be exploited in the analysis. Figure 5 is a map that shows a random distribution of the extracted checkout points from the provided airborne laser scanning point clouds at the test site area. The layer of the ground truth external checkout points is viewed over the aerial image matching DSM of 0.090 m ground resolution of the test site. Also, the results of the statistical analysis of elevation residual are depicted in Table 3.

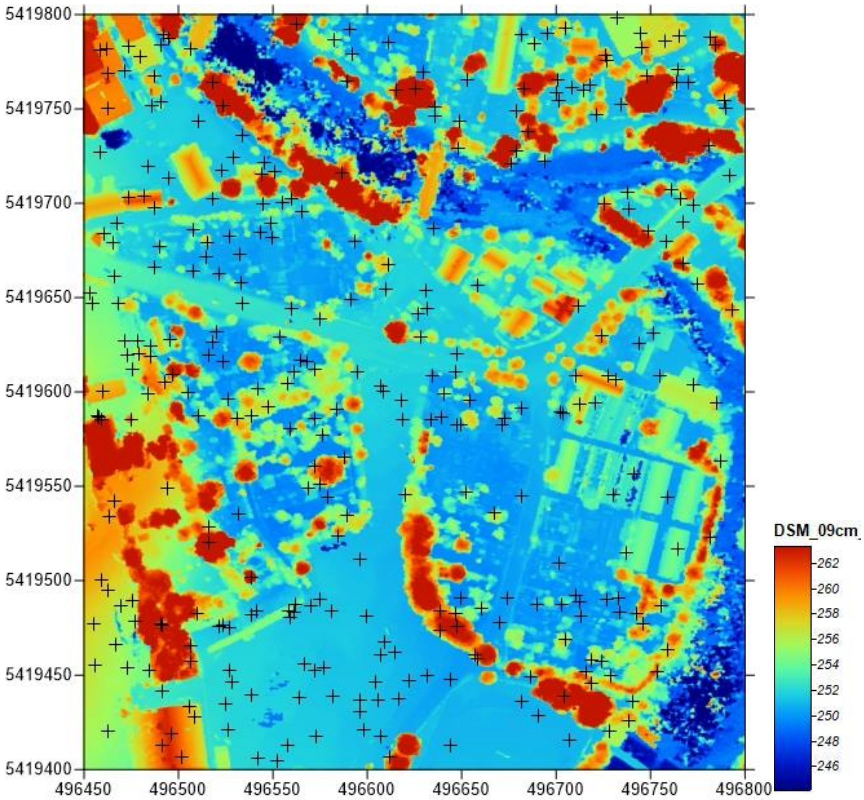


**Fig. 5.** Random distribution of the external checkout points over the test site area viewed over an aerial image matching DSM of 0.090 m ground resolution for the test site.

From table 3 a number of 325 external checkout points have been used in the analysis for accuracy estimation of the aerial imagery DSM extracted with the automated methods. The statistical values of the analysis of residual elevations are close for both DSMs of 0.09- and 0.14135-meter ground resolutions. This means that such small variation in the ground resolution of the DSM did not leave a great effect on the extracted elevations from the DSMs. This appears in the similar values of the ranges of residuals and the mean residuals as well as the median residuals and the standard error of the mean of residuals. However, regarding the standard error of the extracted residual elevations it can be seen that, the DSM of 0.09 meters ground resolution is slightly more accurate compared to the DSM of 0.14315 meters of ground resolutions.

**Table 3:** Statistical analysis of the computed elevation residuals from two DSMs extracted at two different resolutions from overlapped aerial imageries with the use of automated methods in rural landscapes.

| Statistical quantity | Rural_09cm_DSM | Rural_14cm_DSM |
|---|---|---|
| Number of external checkout points | 325 | 325 |
| Number of missing values | 0 | 0 |
| Sum of Residuals (meters) | -173.441 | -173.386 |
| Minimum Residual (meters) | -10.985 | -10.985 |
| Maximum Residual (meters) | 4.906 | 4.906 |
| Range of Residuals (meters) | 15.891 | 15.891 |
| Mean Residuals (meters) | -0.534 | -0.533 |
| Median of Residuals (meters) | 0.023 | 0.023 |
| Standard error of Residuals (meters) | 2.044 | 2.046 |
| Standard Error of the Mean Residuals (meters) | 0.113 | 0.113 |

## 4.5. Feature Extraction from the Image Matching DSM

Figures 6 and 7 are cross profile sliced in a business building with the use of Surfer 10 software from the DSMs extracted from aerial imagery DSMs at ground resolutions of 0.09 and 0.14315 meters respectively. The business building is located at the west bank of the river that appears in the ortho image of the test site in Figure 1. Apart from some spikes it can be said that fine shapes of the different bays of the business building have been extracted. Thus, editing of both DSMs that can be done with the help of some software can help removal of such spikes and save extraction of better geometrical shapes of the multi-bay building that can be close to the real world.

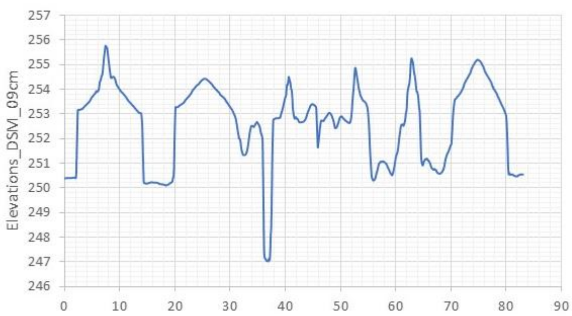


**Fig. 6:** Cross profile in a business building sliced from aerial imagery DSM extracted with the use of automated methods at a spatial resolution of 0.90 meters.

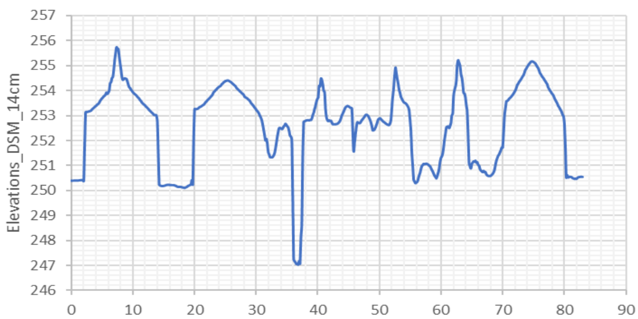


**Fig. 7:** Cross profile in a business building sliced from aerial imagery DSM extracted with the use of automated methods at a spatial resolution of 0.14315 meters.

Also, Figures 8 and 9 are longitudinal profiles in a paved road sliced from aerial imagery DSMs extracted with the use of automated methods at spatial resolutions of 0.90 and 0.14315 meters respectively in rural landscapes. The road is located at the north part of the test site. Clear spikes appear in the longitudinal profiles from the DSMs of different resolutions. Removal of these spikes from the DSM would lead to better longitudinal profiles that can be close to the real world. However, it seems that image matching algorithms work well at ground elevation features such as roads compared to their performance at the buildings and complicated structures.

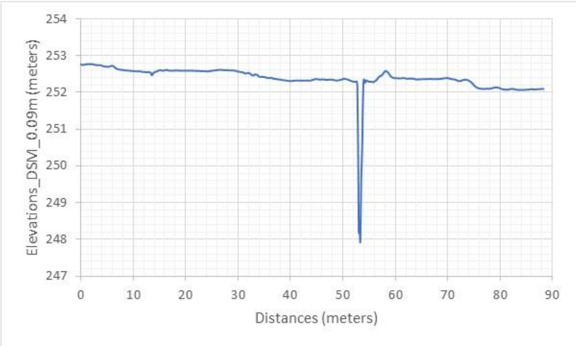


**Fig. 8:** Longitudinal profile in a paved road sliced from aerial imagery DSM extracted with the use of automated methods at a spatial resolution of 0.90 meters.

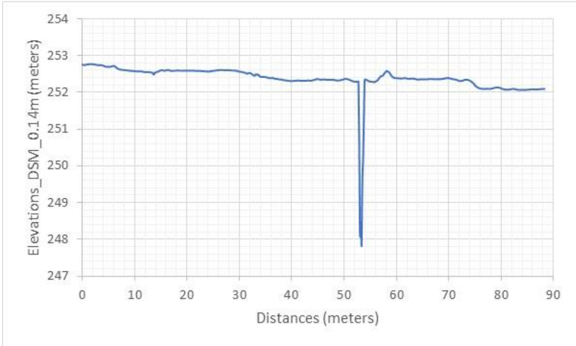


**Fig. 9:** Longitudinal profile in a paved road sliced from aerial imagery DSM extracted with the use of automated methods at a spatial resolution of 0.14315 meters.

# CONCLUSIONS

Automated DSM generation through the application of image matching techniques on digital image stereo pairs has gained great interests in recent years. Various image matching algorithms have been developed and have become commercially available including area-based image matching, feature-based image matching method and symbolic-based image matching. This research aimed at examining the efficiency of the DSMs extracted from aerial imagery stereo pairs with the use of automated methods in modelling of rural landscapes in addition to assessment of the quality of such DSMs at varying ground resolutions. The test data used in this study is a clipped DSM from the whole DSM created from aerial imagery stereo pairs with the use of automated methods at Vaihingen city in Germany. The provided DSM for Vaihingen city has been extracted from the original aerial imagery stereo pairs with the use of dense matching model under the Match-T DSM software [20]. From the analysis the following points can be concluded:

1) Visual analysis of the two DSMs created with the use of dense matching algorithm shows clear and fine representation of the different features in both DSMs of 0.09 and 0.14315 meter ground resolutions. However, the differences between the two DSMs are hardly noticeable visually.
2) Corresponding statistical quantities including the maximum elevations and minimum elevations are not far from each others in both DSMs with wider ranges of elevations and higher standard deviation in the DSM of 0.09 meters that can be due to the effect of elevation smoothing in the DSM of 0.14315 meters ground resolution.
3) Creation of DSMs with fully automated methods requires editing operations for removal of the arising spikes that could affect the statistical analysis quantities of the DSMs.
4) The standard error of the extracted residual elevations from the DSM of 0.09 meters ground resolution is smaller than that from the DSM of 0.14315 meters which means the residual elevations from DSM of 0.09 meters are slightly more accurate than those extracted from the DSMs of 0.14315 meters of ground resolutions using the same sample of checkout points.

5) Feature extraction from the DSMs shows that apart from a few spikes it can be said that fine shapes of the different bays of the business building have been extracted. However, editing of the DSMs for removal of such spikes can help extraction of better geometrical shapes of the features that can be close to the real world.
6) Image matching algorithms work well at ground elevation features such as roads compared to their performance at buildings and complicated structures.


## ACKNOWLEDGEMENTS

"The Vaihingen data set was provided by the German Society for Photogrammetry, Remote Sensing and Geoinformation (DGPF) [19]".


## CONFLICT OF INTEREST

The author has no financial interest to declare in relation to the content of this article.

## REFERENCES


[1] H. Dibs, and N. Al-Ansari, "Integrating highly spatial satellite image for 3d buildings modelling using geospatial algorithms and architecture environment," Engineering, vol. 15, pp. 220-233, 2023. https://doi.org/10.4236/eng.2023.154017.

[2] S. Kosov, F. Rottensteine, C. Heipke, J. S. Leitloff, S. Hinz, "3D classification of crossroads from multiple aerial images using markov random fields." The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 39(B3), pp. 479-484, 2012.

[3] A. Ghafoor, R.N., Iqbal, S. Nabi, "Robust image matching algorithm" Video / Image Processing and Multimedia Communications, Zagreb. Croatia, 2-5 July 2003, pp. 155 - 160.

[4] L. Li; P. Fuyuan; Z. Kun, "Simplified SIFT algorithm for fast image matching," Infrared Laser Engineering Vol. 37, pp. 181–184. 2008.

[5] L. Tang, S. Ma, X. Ma, H. You, "Research on image matching of improved SIFT algorithm based on stability factor and feature descriptor simplification" Applied. Sciences., 12, 8448, 2022.

[6] F. Rottensteiner, G. Sohn, M. Gerke, J. D. Wegner, "ISPRS test project on urban classification and 3d building reconstruction," ISPRS - Commission III - Photogrammetric Computer Vision and Image Analysis, Working Group III / 4 - 3D Scene Analysis, 2013.

[7] S. Yin, Y. Zhu, H.; Hong, T. Yang, Y. Chen, Y. Tian, "DSM extraction based on Gaofen-6 satellite high-resolution cross-track images with wide field of view," Sensors, 23, 3497, 2023.

[8] V. Spreckels, L. Syrek, A. Schlienkamp, "DGPF project: evaluation of digital photogrammetric camera systems – stereoplotting," Photogrammetrie – Fernerkundung – Geoinformation, vol. pp. 2117-130, 2010.

[9] W. Yang, X. Li, B. Yang, Y. Fu, "A novel stereo matching algorithm for digital surface model (dsm) generation in water areas". Remote Sensing, 12, 870. 2020; doi:10.3390/rs12050870 www.mdpi.com/journal/remotesensing.

[10] L. Si, X. Hu, B. Liu, "Image matching algorithm based on the pattern recognition genetic algorithm," Computational Intelligence and Neuroscience, 1-9. 10.1155/2022/7760437, 2022.

[11] J. Wang, K. Gong, T. Balz, N. Haala, U. Soergel, L. Zhang, M. Liao, "Radargrammetric DSM Generation by Semi-Global Matching and Evaluation of Penalty Functions," Remote Sensing, 14, 1778, 2022.

[12] J. Ma, X. Jiang, A. Fan, J. Jiang, J. Yan, "Image matching from handcrafted to deep features: A survey," International Journal Computer Vission, vol. 129, pp. 23–79, 2021.

[13] Z. Hossein-Nejad, H. Agahi, A. Mahmoodzadeh, "Image matching based on the adaptive redundant keypoint elimination method in the SIFT algorithm". Pattern Analysis Application Vol. 24, 669–683, 2021.

[14] X. Jiang, J. Ma, G. Xiao, Z. Shao, X. Guo, "A review of multimodal image matching: Methods and applications" Inf. Fusion, vol. 73, pp. 22–71, 2021.

[15] I. Balenović, H. Marjanović, I. Vuletić, E. Paladinić, M. Sever, K. Indir, "Quality assessment of high density digital surface model over different land cover classes," Periodicum Biologorum, UDC 57:61, Vol 117, No 4, 2015.

[16] G. Kuschka, P. d’Angeloa, R. Qinb, D. Polic, P. Reinartza, D. Cremers, “DSM accuracy evaluation for the ISPRS commission i image matching benchmark,” The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, ISPRS Technical Commission I Symposium, Denver, Colorado, USA, 17 – 20 November 2014, Volume XL-1, 2014.
[17] A. Mahphood, H. Arefi, A. Hosseininaveh, A. Naeini, “Dense multi-view image matching for DSM generation from satellite images”. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, GeoSpatial Conference 2019 – Joint Conferences of SMPR and GI Research, Karaj, Iran, 12–14 October 2019, Volume XLII-4/W18, 2019.
[18] M. L. Hobi, C. Ginzler, “Accuracy assessment of digital surface models based on WorldView-2 and ADS80 stereo remote sensing data” Sensors, vol. 12, pp. 6347-6368; 2012. doi:10.3390/s120506347.
[19] M. Cramer,. The DGPF test on digital aerial camera evaluation – overview and test design. Photogrammetrie – Fernerkundung – Geoinformation vol., 2(2010):pp. 73-82, 2010.
[20] C. Lemaire, “Aspects of the DSM production with high resolution images. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol., 37(B4), pp. 1143-1146, 2008.
[21] N. Haala, H. Hastedt, K. Wolf, C. Ressl, S. Baltrusch, “Digital photogrammetric camera evaluation – generation of digital elevation models”. Photogrammetrie – Fernerkundung – Geoinformation vol., 2(2010):pp. 99-115, 2010.