COMPARATIVE STUDY ON DIGITAL TERRAIN MODELS CREATED BASED ON ALS DATA AND PLEIADES IMAGES

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*   **Abstract:** Digital terrain models are used in a wide variety of domains and applications, of which the most important are: orthorectification of aerial and satellite images, space object modelling, hydrological modelling, etc. There are several techniques for data acquisition in order to create digital terrain models, such as photogrammetry, radargrammetry, interferometry, airborne laser scanning, surveying and geodetic and cartographic digitization. This paper aims to present a comparison betweenthe digital terrain models created based on ALS data, respectively Pleiades satellite images. To achieve results, first was created the digital terrain model based on ALS data, using an interpolation grid side of 1m and moving planes interpolation method. Then, the digital terrain modelof the same area, was created based on highly dense point cloud, obtained automatically by matching two Pleiades images, using the feature-based and least-squares matching techniques. A comparative study was made on these two digital terrain models, by performing the vertical differencebetween them, using the Hausdorff distance.*

        Keywords:digital terrain model, Pleiades satellite image, vertical difference

1. Introduction

        Since their origin in late 1950s, digital models have found wide applications in various disciplines such as remote sensing, mapping, civil engineering, mining engineering, geology, geomorphology, land planning, and communications [1].
        In order to obtain the digital models, many source data can be used such as: GNSS for direct data acquisition, photogrammetry,aerial and space images, radargrammetry and SAR interferometry, airborne laser scanning, existing topographic maps.
        The airborne laser scanning (ALS) is becoming an important operational tool in remote sensing over the past decades, due to advancements in reliability and resolution. The usefulness of ALS systems has been demonstrated by a number of applications where traditional photogrammetric methods fail or become too expensive, for example, the acquisition of terrain elevation data over areas with dense vegetation [1] or acquisition of 3D city data [2], [3].
        The satellite images are not widely used for acquisition of data for digital terrain models. However, with high-resolution images such as Pleiades 1A and Pleiades 1B images with 0.5 m resolution, space images will find more applications in DTM generation.

2. Presentation of the Study Area,Materials and Equipment

2.1. Presentation of the Study Area

The study area is centered at N47°43′, E16°22′, which is approximately 55km south of Vienna, in Burgenland stateof Austria(Fig. 1). In order to create the Digital Terrain Model and the DigitalSurface Model an area of 250 by 250 meters was selected.The terrain of our first plot is moderate in slope, with elevation from 321 to 344 meters above the sea, covered by low vegetation and trees.

<table>
<tr><td>(a)</td><td>(b)</td></tr>
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Fig. 1. (a) Location of the study area and (b) detail

2.2. Materials and Equipment

The data used in this study were provided by the Department of Geodesy and Geoinformation, from Vienna University of Technology.

The airborne data have been obtained by two airborne LiDAR sensors: Riegl LMS-Q560 and LMS-Q680, both with a maximal pulse repetition rate of 240 kHz and laser wavelength in near infrared. The data acquisition took place from 6st till 21st of April 2010. The point density in non-overlapping areas was between 4 points/m2 and 8 points/m2[4].The ALS points have accuracy under 30 cm in horizontal plane and 15 cm in vertical plane.

The satellite data used in this study is Pleiades 1B panchromatic image. The spatial resolution of analysis image is less than 0.7 meter by pixel. The stereo satellite images were captured consecutively by satellite Pleiades 1B, along the same orbit within a few seconds. The acquisition date is 24 September 2014, at 9:59 a.m.

2.3 Data processing

In order to obtain the DTM and the DSM of the study area, based on Pleiades satellite images, the INPHO GmbH software MATCH-T DSM was used.The software works in an iterative process from a coarse approximation to the final high accurate results.Using matching methods like Least Squares Matching (LSM), Feature Based Matching (FBM) and Cost Based Matching (CBM) it producesa highly precise measurement that brings DTM accuracy to a level comparable to conventional DTM measuring methods [5]. A complete description of the MATCH-T design can be found in [6].

For the ALS point cloud processing, OPALS (Orientation and Processing of Airborne Laser Scanning data) software package was used, developed by the Technical University of Vienna [7]. Opals software has a modular structure, each module having a well-defined area of activity.

In order to compare the Digital Terrain Model and the Digital Surface Model, obtain from ALS data and satellite image, respectively theHausdorff distance implemented into "*CloudCompare*" software was used. "*CloudCompare*" is an open source tool designed to perform comparison between two 3D point clouds or between a point cloud and a triangular mesh.

## 3. RESULTS AND DISCUSSION

3.1 Obtaining the DTM of the study area

Digital terrain model (DTM) is simply a statistical representation of the continuous surface of the ground, by a large number of selected points with known X, Y, Z coordinates in an arbitrary coordinate field [3].

3.1.1 Obtaining the DTM of the study area based on Pleiades satellite images

To transform the satellite images into point clouds,the "*MATCH-T DSM*"software was used. The features of point clouds that represent the terrain were undulating, for the terrain type with low smoothing and dense feature density, which means that every pixel row was used. Point cloud density was 3 pixels, meaning that a point for each 3 pixel row and 3 columns was obtained. So, a point cloud that contains2325 points was created.

To obtain the DTM from the resulted point cloud, the "MovingPlanes" interpolation method was applied in OPALS, using the search radius of 10 m and 20 neighbours (Fig. 2a). It can be observed that the resulted DTM presents large area without elevation information. Therefore, parameters of "MovingPlanes" interpolation method were modified increasing the radius to 30 m and the neighbours number to 50 (Fig. 2b). Through the high value of radius the precision of the model decreases.

The DTM can be viewed in 3D in different color palettes using "*ArcScene*" software (Fig. 2 c, d).

(a)   (b)

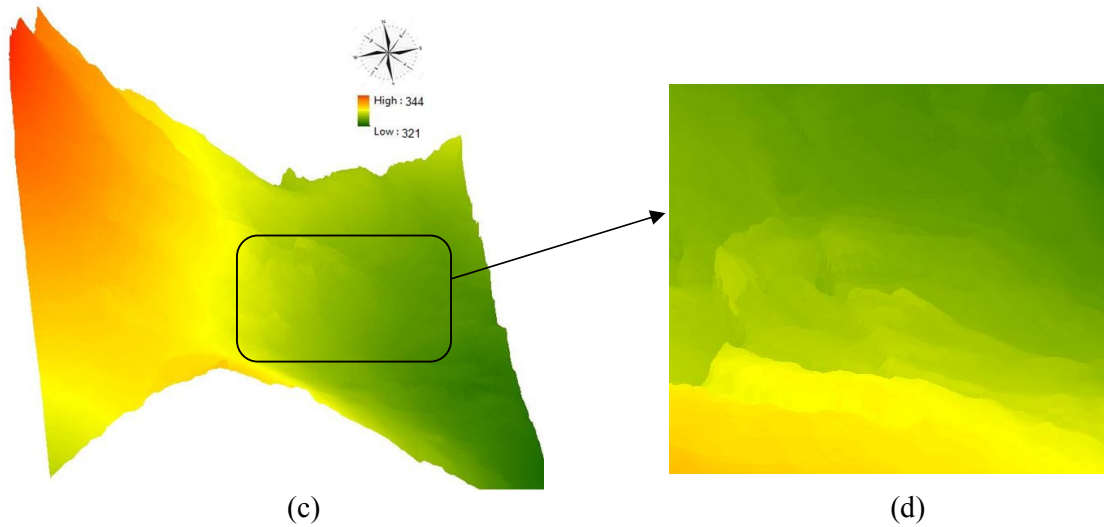(c)   (d)
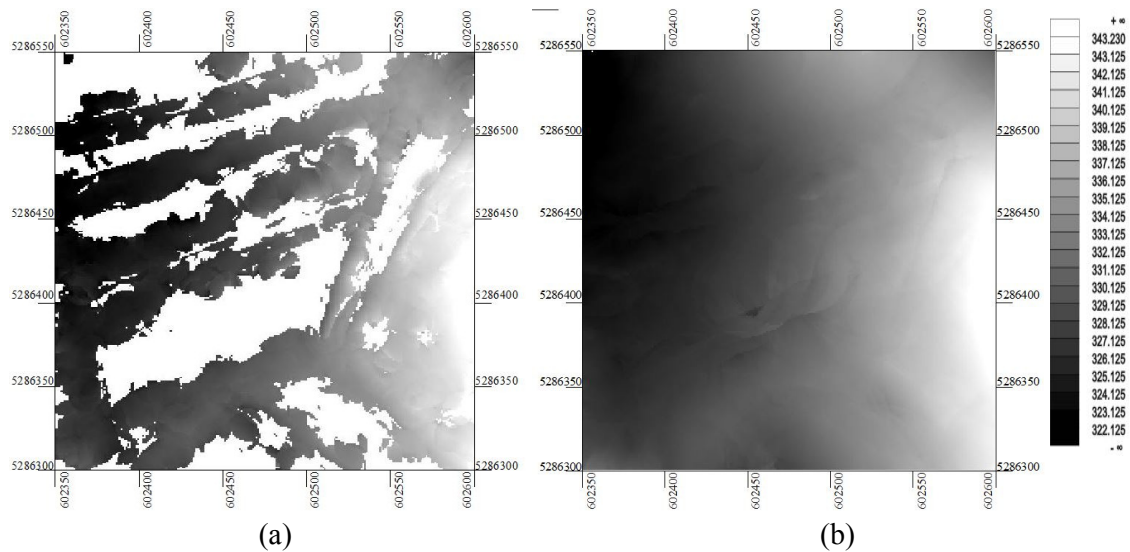
Fig. 2. (a) DTM raster obtained by "movingPlanes" interpolation method (1m cell size; 20 neighbours; 10 m search radius), (b) DTM raster obtained by "movingPlanes" interpolation method (1m cell size; 50 neighbours; 30 m search radius) (c) DTM raster perspective view in 3D and (d) detail view in "ArcScene"

3.1.2 Obtaining the DTM of the study area based on ALS data

The Digital Terrain Model based on ALS data was obtained using the "OpalsGrid"module, "movingPlanes" interpolation method with 1 m cell size, 8 neighbours and 1 m search radius. Because of the large number of points, the cell size and the search radius were lower than the values used in the case of satellite images.

The Digital Terrain Model can be viewed in different modes and in different color palettes, using "OpalsZColor" or "OpalsShade" modules, as can be seen in Fig. 3a and 3b.

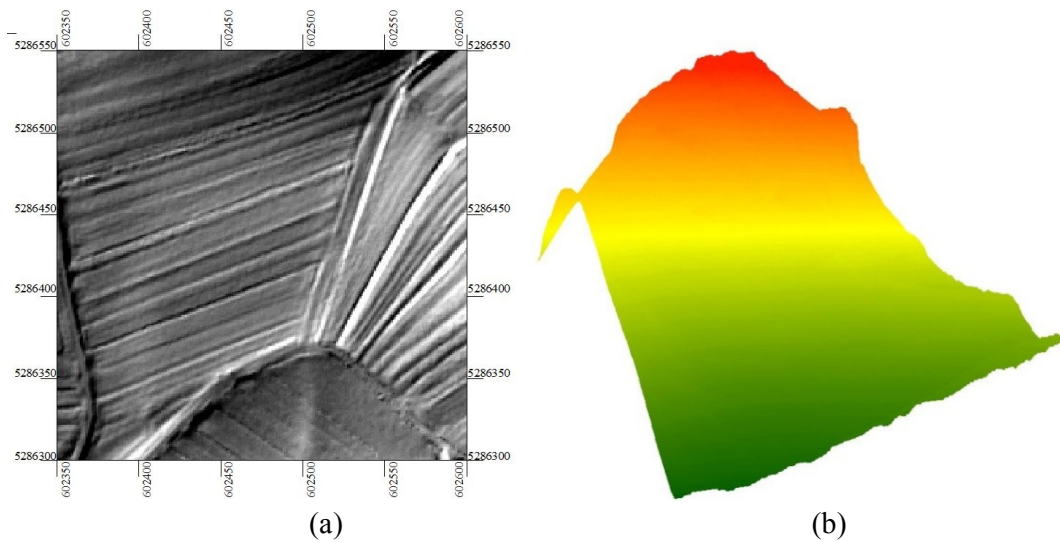(a)   (b)

Fig. 3. Digital Terrain Model of the study area represented in raster format (1m cell size, 8 neighbours and 1 m search radius) (a) hillshade ecolor palette , (b)standard color palette- 3D view in "ArcScene"

3.2 Obtaining the DSM of the study area

Digital surface model (DSM) is similar to the DTM, except that the DSM contains the altitudes of the reflectance surface of buildings roofs, trees and other components of the earth's surface [8].

3.2.1 Obtaining the DSM of the study area based on Pleiades satellite images

To obtain the Digital Surface Model, were followed the same steps as in the Digital Terrain Model cases. Using the"*MATCH-T DSM"* software, a point cloud containing32522 points was obtained.

In order to create the Digital Surface Model, the "movingPlanes" interpolation, with 1 m cell size, 10 neighbours and 1 m search radius, was used. The DSM can be viewed in different color palettes, using "OpalsZColor" or "OpalsShade" modules (Fig. 4a and 4b).
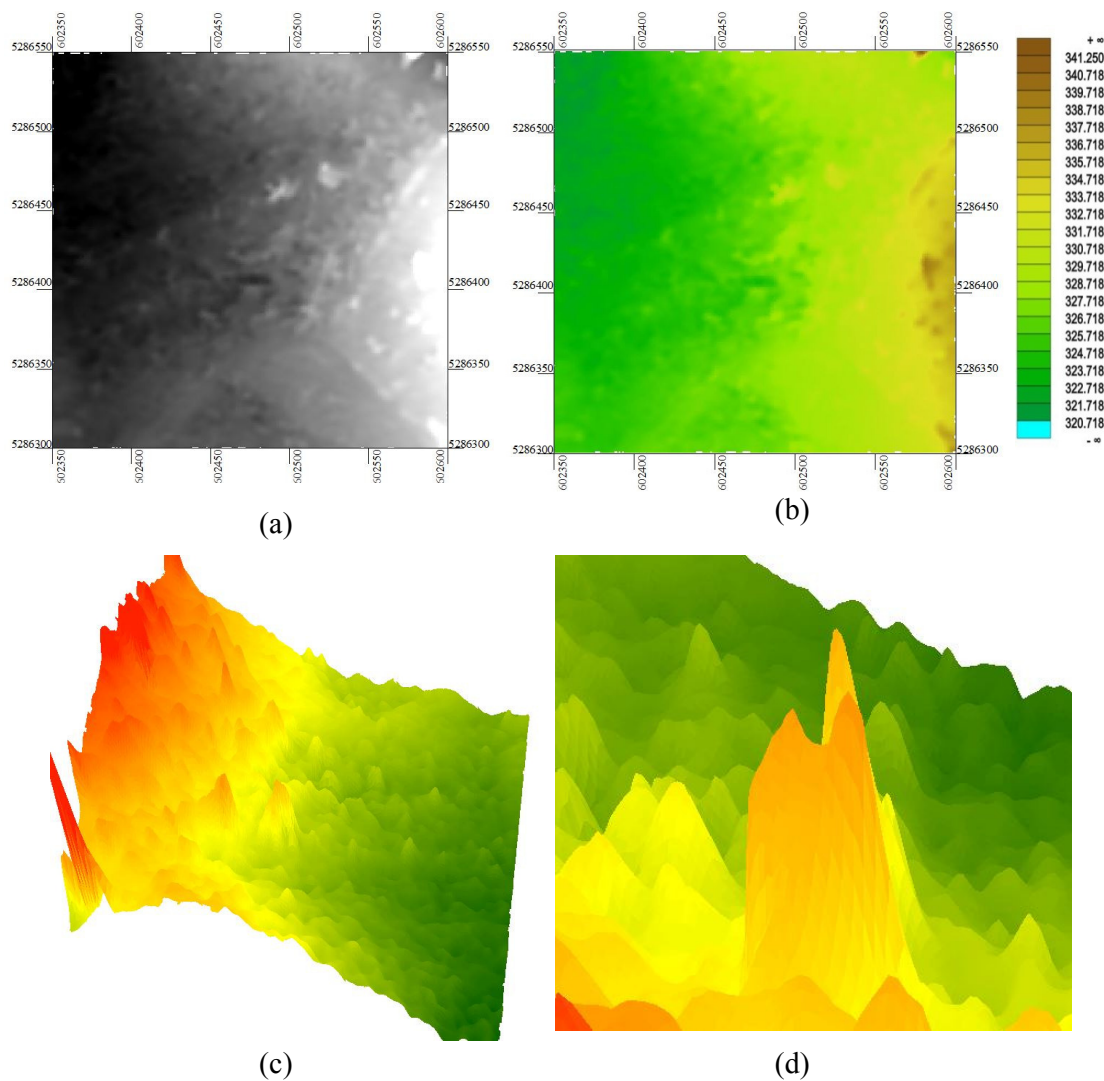

(a)   (b)

(c)   (d)

Fig. 4.(a) The DSM raster obtained by "movingPlanes" interpolation method (1m cell size; 10 neighbours; 1 m search radius), (b)standard color palette, (c) DSM raster perspectiveview in 3D and (d) detail view in "ArcScene"

3.2.2 Obtaining the DSM of the study area based on ALS data

The Digital Surface Model was obtained by interpolating all ALS points, using "OpalsGrid" module, "movingPlanes" interpolation method with 1 m cell size, 8 neighbours and 1 m search radius. In order to view the digital models, in different modes and in different color, the „OpalsZColor" and „OpalsShade" modules were used [9]. The color palettes such as standard palette, grey palette, hillshade, slope, helps operator in reviewing and analyzing process.

In Fig.5a, the DSM is highlighted by a colored raster using the "standard" color palette and in Fig. 5b by a hillshade raster, with a spatial resolution of 1 m. The details of DSM can be observed in Fig. 5c and 5d.
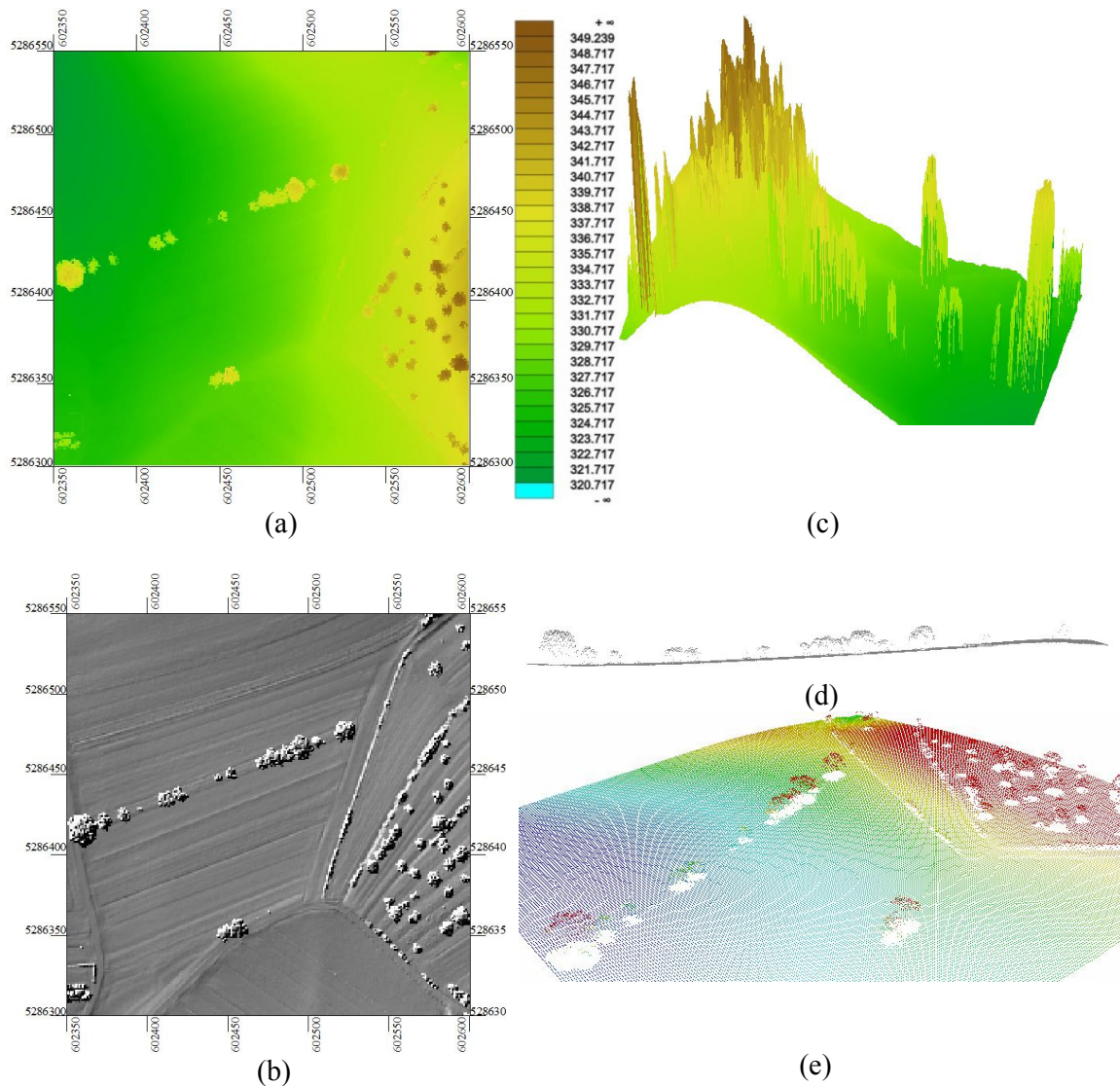
Fig. 5.The Digital Surface Model of the study area represented in raster format (1m cell size) (a) standard color palette, (b) hillshade, (c) 3D visualization of DSM in "ArcScene" (d) profile and (e) 3D visualization of the DSM point cloud in "FugroViewer"

3.3 Comparison between the DTM and the DSM of the study area obtained based on Pleiades images and ALS data, respectively

In order to compare the DTM and the DSM of the study area, obtained based on Pleiades images and ALS data, respectively, the corresponding point clouds were imported into the „CloudCompare v.2.6.2" software, where, first two triangular meshes were created by the Delaunay triangulation interpolation method. Then, the two meshes were compared, considering as reference surface the one resulted from satellite images, using as comparison metric the signed Hausdorff distance and the octree level 8 [10].

After comparing the Digital Terrain Models created based on the two data sources mentioned above, a maximum negative difference of -8.30 m, a maximum positive difference of 4.33 m, a mean difference of -1.81 cm and the standard deviation of 0.71 cm were obtained.

After comparing the Digital Surfaces Models a maximum positive difference of 14.46 m was obtained, representing the horizontal translation between the two data sets and a standard deviation of 1.33 m (Fig. 6).
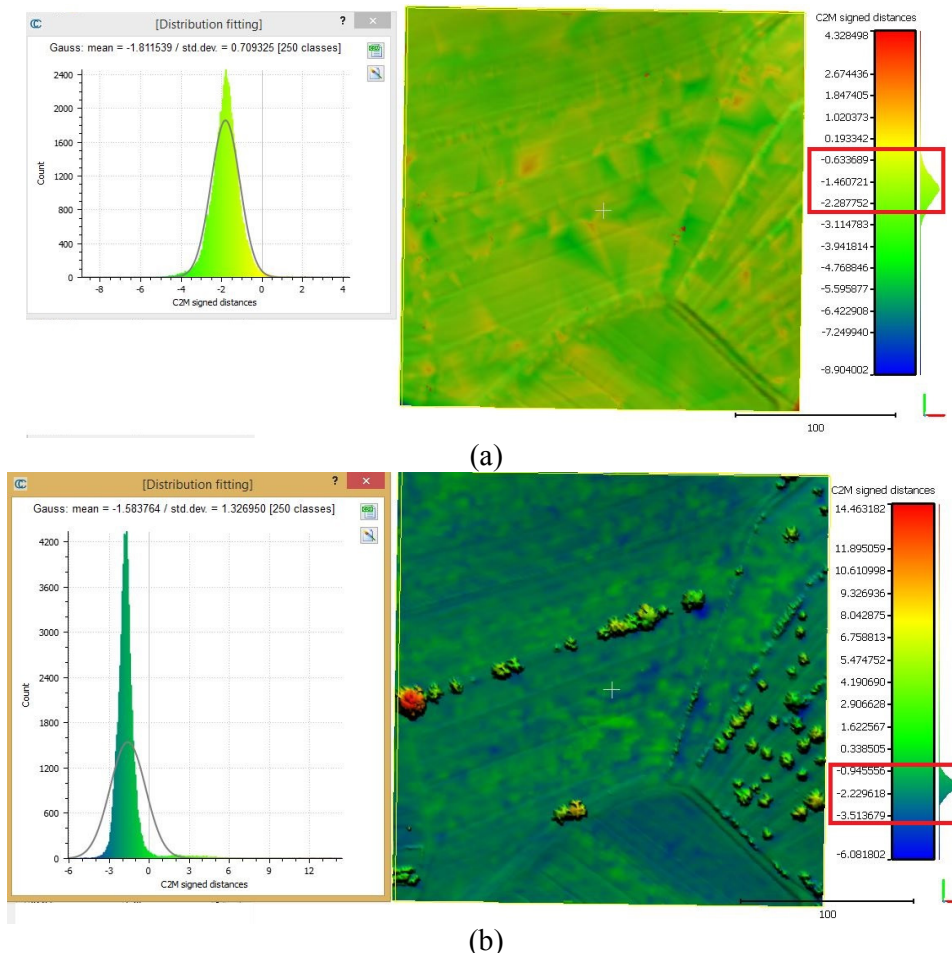

(a)

(b)

Fig. 6. The differences between the digital models created based on ALS data and satellite images (a) DTM, (b) DSM

In case of DSM, huge differences of almost 15 meters, appeared in areas with high vegetation, caused by the acquisition time difference of almost 4 years, between ALS data and satellite images.

Tabel1. Differences between the DTM and the DSM of the study area obtained based on Pleiades images and ALS data, calculated using the Hausdorff distance

Differences	DTM	DSM
Positive differences	4.30 m	14.46 m
Negative differences	-8.90 m	-6.08 m
Mean differences	1.81 m	1.58 m
Standard deviation	0.71 m	1.33 m

4. Conclusions

In this paper the Digital Terrain Model and the Digital Surface Model of a selected study area, were created based on two data sources, namely ALS data and very high resolution satellite images, then were compared by using the Hausdorff distance and the "*CloudCompare*" software.

It was observed that the point cloud created based on satellite images that represents the DTM, have a small number of points. This issue it forced us to use a high number of neighbours and a bigger search area to create the DTM, leading to a poor precision of the model. The number of points can be increase if another feature is used to create the DTM, but the process takes a long time and a performance computer is needed.

In the DSM case, the big values for the differences are highlighting the existence of high vegetation, caused by the acquisition time difference of almost 4 years, between ALS data and satellite images.

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