METHODS FOR GENERATING THE DIGITAL TERRAIN MODEL, DIGITAL SURFACE MODEL AND ORTHOMOSAIC USING UAV AND GNSS TECHNOLOGY

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Abstract. *The purpose of this article is to accomplish a Digital Terrain Model, Digital Surface Model and an orthophotoplan - orthomosaic of an area within the Didactic and Experimental Resort of BUASVM Timisoara based on geomatic technologies. The interest for UAVs has been constantly growing, researchers and developers use a lot of resources and efforts to contribute to this topic, especially in applications of geomatics in various fields such as: agricultural and forestry, autonomous surveillance (Herbei and Sala, 2020), emergency and disaster management, traffic management and 3D mapping with photogrammetry. This increase is mainly due to the fact that UAV systems are a reliable and low-cost alternative, fast speed, high maneuverability and high security for image collection. A DJI Phantom 4 drone was used in this work. Phantom IV is a system composed of a drone (UAV) and a mobile RTK station and is suitable for aerial photography and aerial filming activities suitable for data processing in order to obtain orthophotoplanes, point clouds or 3D modeling. Most drones have built-in GPS, IMU (inertial measurement unit) and barometric altimeter, to help navigation. The default positional accuracy is generally good enough for many GIS applications. For example, the DJI Phantom 3 Pro has a position accuracy of ± 1m. If necessary, you can improve position accuracy using ground control points (GCPs), see Ground control points. Ground control points (GCPs) are used in image processing to improve the positional accuracy of data. GCPs are physical locations marked with a fixed position, the coordinates of which have been accurately determined (for example, using a combination of navigation systems, such as GPS and GLONASS, or by using differential GPS). In order to purchase images from the field with UAV technology, the Pix4D application and a mobile tool with Android OS were used, which allowed the realization of the flight plan to acquire the images from the desired location.*

Keywords: *UAV, DJI Phantom, Pix4D, DTM, DSM*

INTRODUCTION

The purpose of this article is to accomplish a Digital Terrain Model, Digital Surface Model and an orthophotoplan - orthomosaic of an area within the Didactic and Experimental Resort of BUASVM Timisoara (HALOIU ET AL., 2019) based on geomatic technologies (HERBEI ET AL., 2012). The interest for UAVs has been constantly growing, researchers and developers use a lot of resources and efforts to contribute to this topic, especially in applications of geomatics in various fields such as: agricultural and forestry (POPESCU ET AL., 2020; HERBEI AND SALA, 2014), autonomous surveillance (HERBEI AND SALA, 2020), emergency and disaster management, traffic management and 3D mapping with photogrammetry (ONIGA ET AL., 2016). This increase is mainly due to the fact that UAV systems are a reliable and low-cost alternative, fast speed, high maneuverability and high security for image collection (ONIGA ET AL.,2018).

MATERIAL AND METHOD

The location of any point in an image can be described with only two coordinates: (x, y). The images are only two-dimensional. The location of any point in the real world can be described by three coordinates: (x, y, z), (latitude, longitude, altitude) etc. The real world is three-dimensional. Photogrammetry is the science of using 2D images to make accurate 3D measurements. To do this, the information lost when capturing the image must be recovered. Drones, also called UAVs (unmanned aerial vehicles) or UASs (unmanned aerial vehicles), are unmanned aircraft on board. The flight path can vary in some degree of autonomy, fully or partially automatically by on-board computers or remotely controlled by a ground pilot. UAVs are programmed to cover a certain area of interest at a set altitude. At a preset time, photos are taken. These photos must overlap (Figure 1) enough (LOGHIN AND ONIGA, 2014) to create a perfect image compiled from the image collage. The amount of overlaps can vary from 60-90% (ONIGA ET AL., 2020).

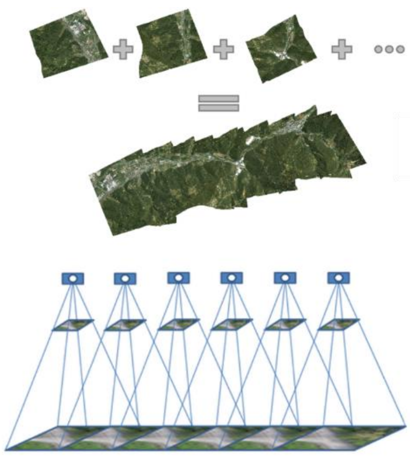

Figure 1. Example of overlapping images taken with a UAV system

The image overlay area specified as a percentage is vital for image processing, such as orthosaturation (image stitching) and digital surface patterns. These types of processing use the science of stereophotogrammetry, also known as Structure from Motion (SfM). Stereophotogrammetry uses several photographic images taken from slightly different positions to estimate the three-dimensional coordinates of points on an object. The basic principle of stereophotogrammetry requires matching the characteristics between images to form a single contiguous pattern. Images must overlap considerably for functions to match multiple images. For 2D products, images must be collected in a regular grid pattern. The recommended overlap for most cases is at least 80% frontal overlap (in terms of flight direction) and at least 70% lateral overlap (between runways) (Figure 2.3).

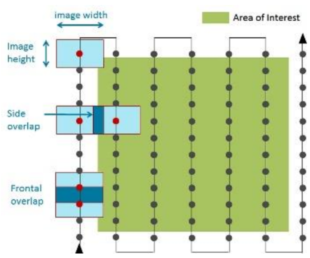

Figure 2.Example of a flight route

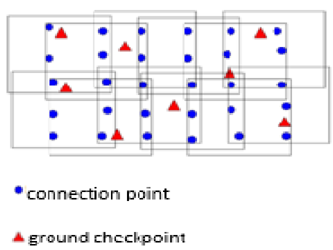

Figure 3.Control points and connection points

Most drones have built-in GPS (ŞMULEAC ET AL., 2019), IMU (inertial measurement unit) and barometric altimeter, to help navigation. The default positional accuracy is generally good enough for many GIS applications (SALA ET AL., 2020). For example, the DJI Phantom 3 Pro has a position accuracy of ± 1m. If necessary, you can improve position accuracy using ground control points (GCPs), see Ground control points. Ground control points (GCPs) are used in image processing to improve the positional accuracy of data. GCPs are physical locations marked with a fixed position, the coordinates of which have been accurately determined (for example, using a combination of navigation systems, such as GPS and GLONASS, or by using differential GPS).

In short, GCPs are essential to provide project accuracy, and checkpoints are used to verify that the position of your data is correct. The most common method for recording GCPs is via a real-time kinematic GPS receiver (RTK), using correction data transmitted from a nearby reference station. Equipment with this degree of positional accuracy is expensive and probably not required for most RSPB applications.

GPCs are collected with high-precision GPS. The points are then imported into the image processing software. After the control points are collected and the aerial photo is entered into the system, the points are manually selected from several photos to obtain high-precision results.

The process of using stereophotogrammetry for mosaic images also creates a cloud of 3D dots and a digital surface model (DSM).

DSM shows the increase of the "peaks" of the photographed objects, at the same resolution as the aerial image. If the vegetation is absent, the values in the DSM will be equivalent to the ground elevation and you will actually have a digital terrain model (DTM) (Figure 4). Otherwise, the DSM value will reflect the surfaces of objects, such as trees and buildings. The absolute elevation of points may be inaccurate when derived using photogrammetry, especially if ground control points are not used, but the relative elevation of a flight should be fairly reliable.

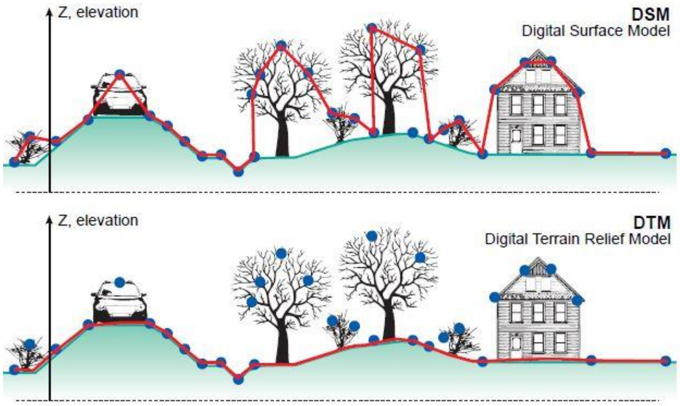

Figure 4. DSM vs DTM (www.charim.net)

RESULTS AND DISCUSSIONS

Image processing from drones with Pix4D software

A DJI Phantom 4 drone was used in this work. Phantom IV is a system composed of a drone (UAV) and a mobile RTK station and is suitable for aerial photography and aerial filming activities suitable for data processing in order to obtain orthophotoplanes, point clouds or 3D modeling.

In order to purchase images from the field with UAV technology, the Pix4D application and a mobile tool with Android OS (STULEANEC AND HERBEI, 2018) were used, which allowed the realization of the flight plan to acquire the images from the desired location.

The workflow for data acquisition and processing is shown in Figure 5.

Figure 5.Data acquisition and processing using the Pix4D application.

After downloading the images from the drone (203 acquisition images - covered area approx. 20 hectares), the Pix4D program was used, following the steps below:

- **Step 1** – Run the Pix4DMapper program and create a new project

During this stage, a new project is created and the destination of its rescue is chosen.

- **Step 2 – Select the images to be processed**

In this step, the photos purchased from the UAV instrument used are added to the previously created project (Figure 6). In this case, the 203 images made with the DJI Phantom IV drone were added.

The photos are geolocated, thanks to the drone's GNSS system, and the program recognized the 1984 WGS system. The program also recognized the model of the camera with which the images were taken.

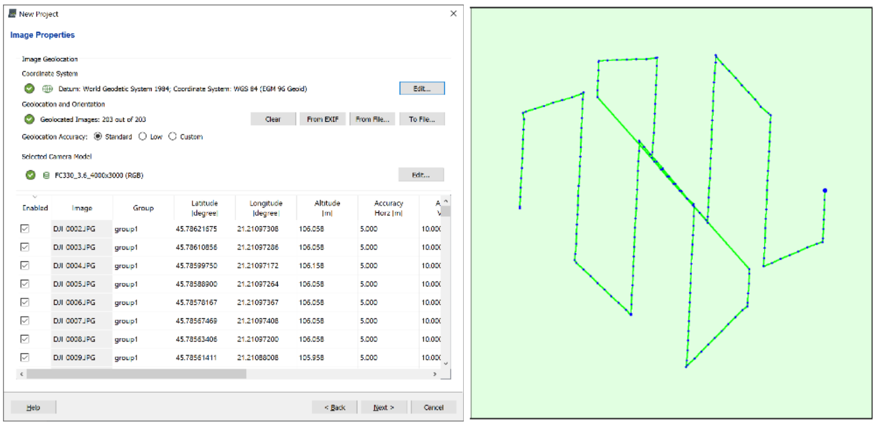

Figure 6. Select the images to be processed

- **Step 3** – Defining the coordinate system

At this step we will select the coordinate system desired by the user. If Ground Control Points - GCP are important, the coordinate system chosen for this step must coincide with the coordinate system of the control points.

In this case, the GCPs were measured in the 1970 Stereo system, so that at this step for the created project the same projection system was chosen - Stereo 70, existing in the program database (Figure 7).

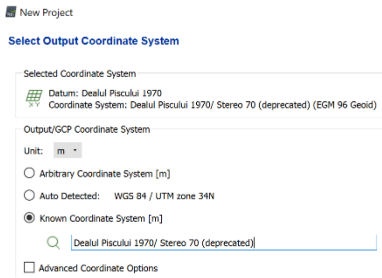

Figure 7. Select the coordinate system

- **Step 4** – Select how to process data from a predefined range

At this step, the data processing format will be selected, which takes into account the resolution, the quality of the final product, the hardware resources and the format of the data obtained after processing.

- **Step 5–** Inserting the GNSS measurements file of the ground control points - GCP to the Pix4D project

GCP- based image processing

Pix4D Desktop can process projects with or without ground control points (GCP). Precise GCPs increase the overall accuracy of the project. There are various methods of using GCP, the following is a very commonly used method

The method used in this research folds very well on the situation when the images taken by UAVs and GCPs have a known coordinate system that can be selected from the Pix4D database or defined from a .prj file.

The two systems do not have to be the same, because Pix4D is able to do the conversion from one system to another. This is the most common case. Allows the user to mark GCPs on images with little manual intervention.

The workflow (Figure 8) based on this method is described in the figure:

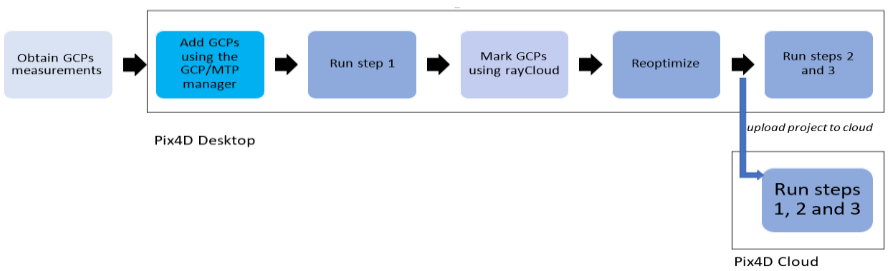

Figure 8. Pix4D workflow (www.pix4D.com)

This method involves the following steps:

- Measurement of GCP points in the field based on GNSS technologies, in this project being used a Leica GS08 GNSS system.
- The import of GCP points with the GCP / MTP Manager option, figure 9, and the location of the control points is observed in figure 10.

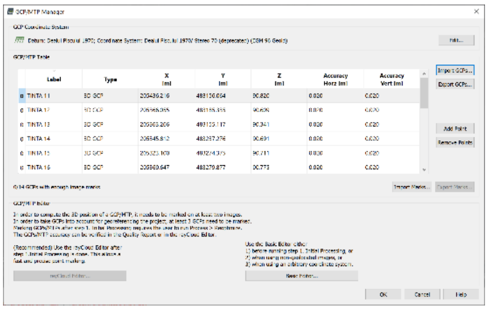

Figure 9. Import GCP points with the option GCP / MTP Manager

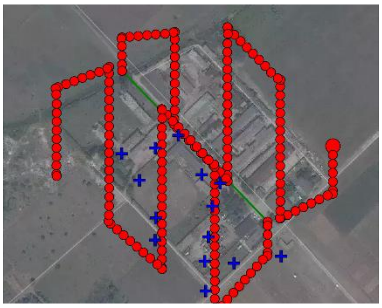

Figure 10. Location of checkpoints

Next, we will start processing the images purchased from the drone, from the View> Processing menu. The processing bar appears at the bottom of the main window and only the Initial Processing option and then the Start button will be checked (Figure 11, 12).

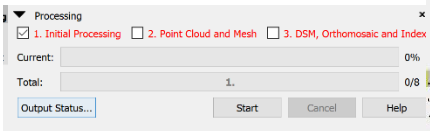

Figure 11. Starting the processing process

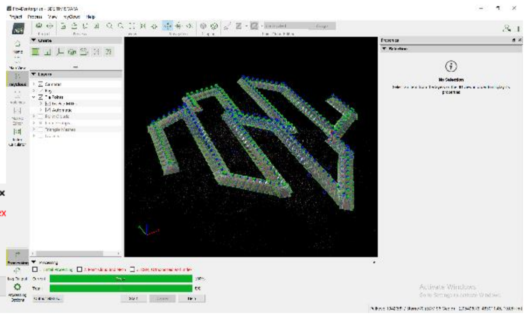

Figure 12. Image processing

After the initial processing is complete, GCP will be marked on the images in the Using the rayCloud drone, following the steps below:

1. The rayCloud option is activated from the View menu.
2. On the left side, in the Layers section, check the Tie Points - GCPs / MTPs option and a list of GCPs measured in the field with GNSS technology will open. In this project, 10 GCPs were chosen from all GCPs measured in the field.
3. Select a GCP in the Layers box - GCPs / MTPs on the right will display the properties of the selected point (name, type, X, Y, Z coordinates, information on the accuracy of the determination, etc.) and ALL images that contain the measured point.
4. Next, mark (click in the center of the ground target) the exact position of each GCP on all the images on which that GCP appears. It is mandatory for a GCP to be marked on at least 2 distinct images.

5. After GCP has been marked on at least 2 images, the Automatic Marking option is chosen

The program will look for the automatic color correlation of the pixel on which the GCP marking was made on the rest of the images. Thus, the GCP position will be optimized based on more images than the ones on which the marking was made, if the color correlation is good.

Images with a green and yellow cross are taken into account during processing. If the cross is green it indicates the correct GCP position and there is no need to mark the dot on multiple images. If the green cross indicates the wrong GCP position, GCP will be marked on multiple images. Each time the GCP is marked on a new image, the green cross approaches the correct location. Check the rest of the images where the yellow mark does not appear. When the green cross is in the correct position in most images, click Apply (Figure 13,14).

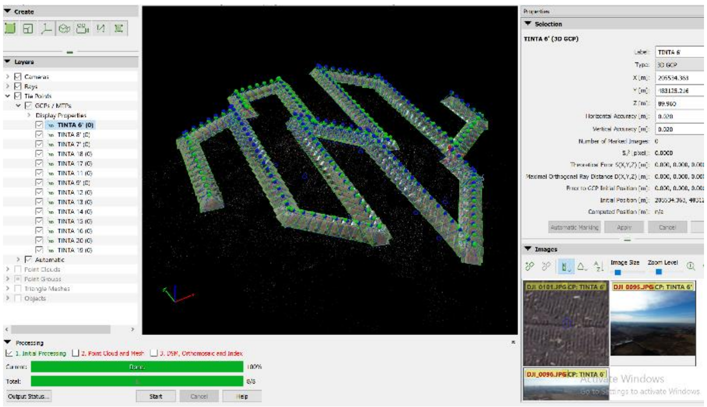

Figure 13. GCP selection

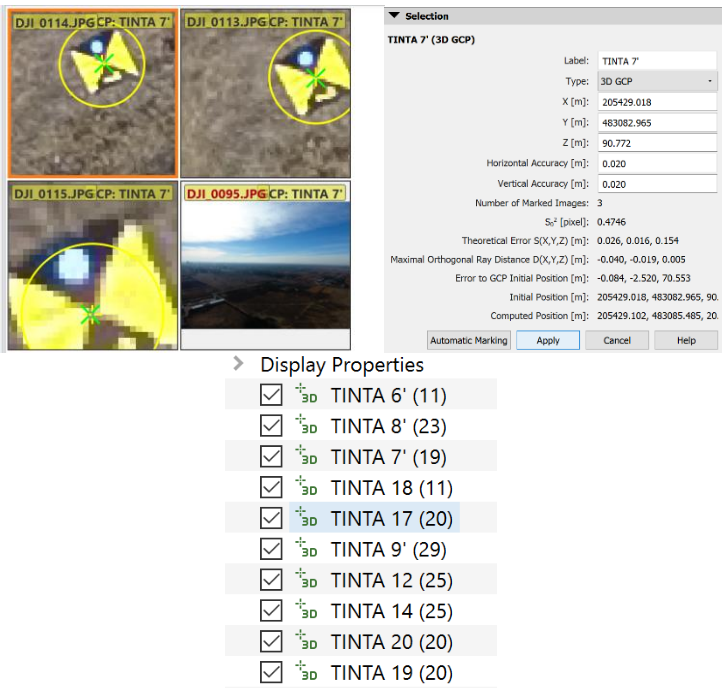

Figure 14. Marking the exact position of a GCP

Steps 1-5 will be repeated for all GCP control points (Figure 15).

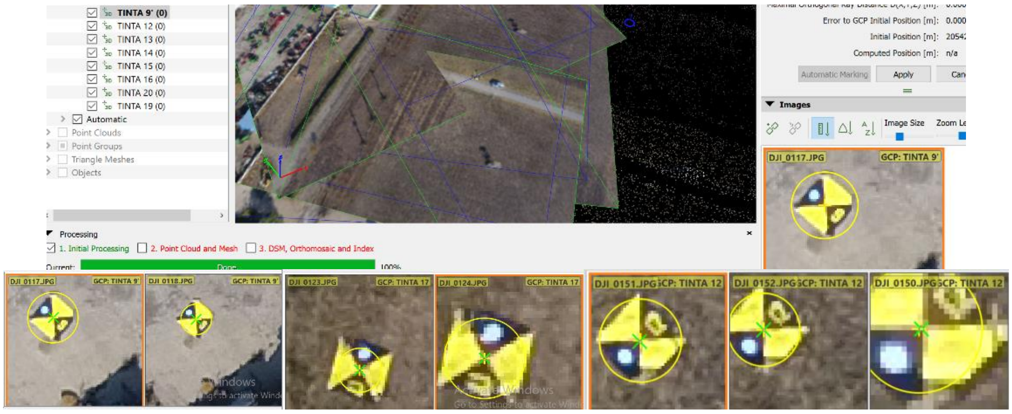

Figure 15. Example of marking the correct position of several GCPs

When all GCPs are marked on the images, choose Process> Reoptimize. This re-optimizes the initial model based on GCP. After re-optimization, a new report will be generated regarding the data processing and their quality. Process> Generate Quality Report. The accuracy of the GCP location (Figure 16, 17) and the average errors in the three coordinate directions. The last column indicates the number of calibrated images in which GCP was automatically checked compared to manual marking.

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
TINTA6' (3D)	0.020/ 0.020	0.203	-0.018	-0.234	0.995	11 / 11
TINTA8' (3D)	0.020/ 0.020	0.067	0.009	-0.045	0.659	23 / 23
TINTA7' (3D)	0.020/ 0.020	-0.043	0.029	0.037	0.616	19 / 19
TINTA 18 (3D)	0.020/ 0.020	0.059	0.005	-0.317	0.737	11 / 11
TINTA 17 (3D)	0.020/ 0.020	-0.002	0.024	-0.046	0.426	20 / 20
TINTA9' (3D)	0.020/ 0.020	-0.032	0.050	-0.002	0.591	29 / 29
TINTA 12 (3D)	0.020/ 0.020	-0.045	-0.001	0.051	0.567	25 / 25
TINTA 14 (3D)	0.020/ 0.020	-0.026	0.011	-0.016	0.542	25 / 25
TINTA20 (3D)	0.020/ 0.020	0.036	-0.077	0.013	0.680	20 / 20
TINTA 19 (3D)	0.020/ 0.020	-0.006	-0.044	0.050	0.707	20 / 20
Mean [m]		0.021015	-0.001292	-0.051066		
Sigma [m]		0.071941	0.035210	0.118399		
RMS Error [m]		0.074948	0.035234	0.128942		

Figure 16. Georeferencing accuracy displayed in the quality ratio

At this moment, the data processing can be continued in order to obtain the Point Cloud, the Mesh structure, the DSM Digital Surface Model and the orthomosaic of the studied area.

Point cloud classification:

The point cloud classification is useful for generating the digital DTM terrain model. This process calculates a classification of point clouds using the densified point cloud that is generated during step 2. Point Cloud and Mesh. Each point is automatically classified into one of the following predefined groups: Soil, Road surface, Vegetation, Building, Man-made object. In the menu bar, choose the option Processing> Execute point cloud classification (Figure 17). The point cloud classification can be viewed in rayCloud and can be exported in various formats (LAS, LAZ, PLY, XYZ), with the right click option on densified point cloud's name Export Point Cloud… Both geometry and color information are used for assign the group of points that form the densified point cloud to one of the predefined groups. Depending on the quality of the data set and the type of terrain, there are areas where the classification works perfectly and manual intervention is required.

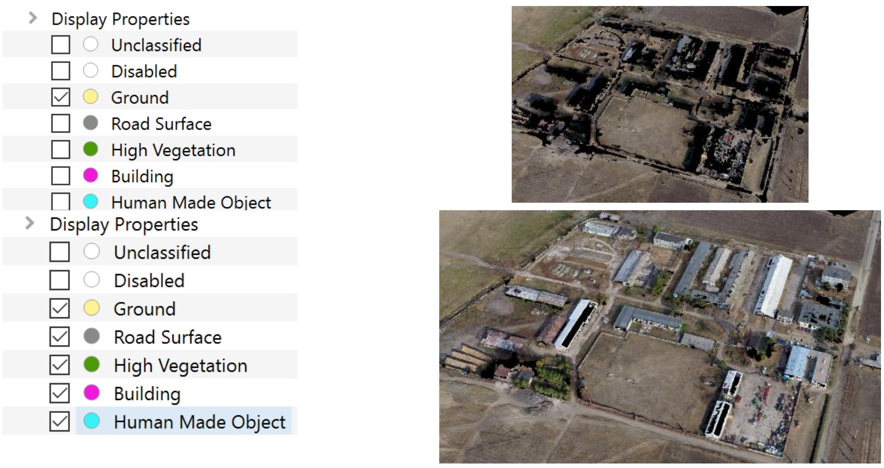

Figure 17. Point cloud classification

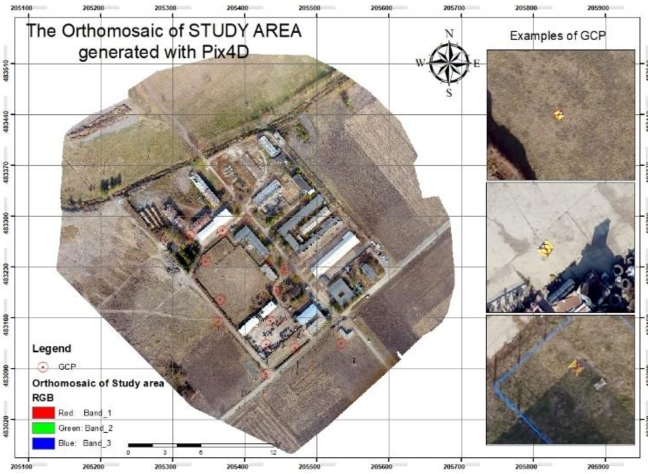

Figure 18. The Orthomosaic of Study Area

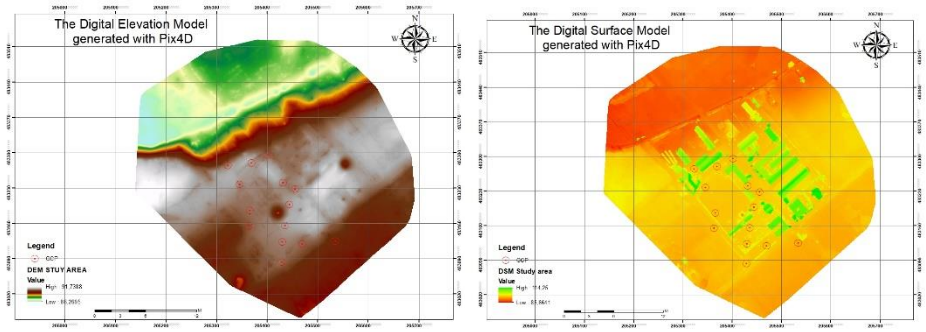

Figure 19. The DTM and DSM of Study Area

CONCLUSIONS

This research wants to analyse the use of images taken by UAV platforms and their processing based on GCP's measured with GNSS technology, in order to make a digital terrain model DTM, a digital surface models DSM and an orthomosaic, with high precision and using specialized software.

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