ADVANCED UAV LIDAR SYSTEM FOR GEOSPATIAL DATA COLLECTION

Octavian BALOTĂ, Lecturer PhD, Universitatea de Științe Agricole și Medicină Veterinară București, octavian.balota@tehnogis.ro
Daniela IORDAN, Lecturer PhD, Universitatea de Științe Agricole și Medicină Veterinară București, iordandaniela5@gmail.com
Gabriel POPESCU, Associate Professor PhD, Universitatea de Științe Agricole și Medicină Veterinară București, gabistpop@yahoo.com
Daniel ILIE, PhD student – Universitatea Tehnică de Construcții București, Prosig Expert SRL, danielilie17@yahoo.com

***Abstract**: There are presented 2 systems based on UAV equipment using a combination of 2 technologies Lidar and photogrammetry. Both UAV equipment, the hexacopter DJI M600 and the fix wing airplane TerraHawk CW-20 with vertical landing are collecting high density of Lidar points and aerial images.*

The paper presents the advantage of using high density of cloud points combined with high image resolution for collecting accurate and complete geospatial data. The registered area is divided in cells and specific algorithms are applied on cells in a tree structure for fast DTM and DSM generation. In house applications are used for cloud data processing and change detection. Some 3D modelling applications are also presented for different kind of objects.

***Keywords:** Lidar; UAV; 3D Modelling; photogrammetry;*

1. Introduction

The UAV systems presented here were realized within the project SYSTEM FOR RAPID MONITORING AND INTERACTIVE MAPPING, co-financed from the European Regional Development Fund through the Operational Program Competitiveness 2014 - 2020, financing contract 124 / 16.09.2016 concluded with the National Research and Innovation Authority as Intermediate Body (OI), on behalf of the Ministry of European Funds (MFE) as Managing Authority (MA) for the Competitiveness Operational Program.

The specific objectives and results of the project were the development of advanced and accurate methodologies based on UAV systems equipped with Lidar and photographic camera for obtaining several geospatial products like "digital topographic map in a GIS structure", "realistic representation of a geographical area" and "landscape change detection complete report". For these products were studied the technical conditions and the optimum steps in the technological process of their generation. The results of this research, some applications and the necessary software solutions developed in the frame of this project are presented in summary below.

2. UAV Systems presentation - technical characteristics and performances

In this research, 3 UAV systems equipped with Lidar and camera were developed, 2 systems based on hexacopter UAV DJI M600 PRO and the other one based on a fix wing UAV CW-20 with vertical landing (Figure 1). The differences for the 2 hexacopters are only the quality of the Lidar sensor, optical camera and IMU.

The DJI MATRICE M600 PRO drone is a professional drone, being one of the most efficient in terms of flight performance (high stability and transport capacity). The pre-installed arms reduce the time required to prepare the UAV system for flight. The ability of these arms to fold, helps in easy transport but also in speeding up the drone mounting. In addition, the ability of rotor propellers to tighten emphasizes these advantages over other air platform solutions available on the market.

The DJI MATRICE M600 PRO platform is equipped with the latest technologies of DJI, being from this point of view a latest generation product. The platform is equipped with the A3 Pro Flight Controller, radio remote control and iPAD PRO 9.7” tablet, Lightbridge 2 HD transmission system, smart battery charging station and high-performance flight batteries. The system also includes flight control software: one for the iPAD PRO tablet, called DJI GO and one for the computer, for connecting systems of the Drone (Lightbridge, D-RTK, ProLink Model, etc.), called DJI Assistant 2.

Fig. 1. LiDAR systems on DJI M600 PRO and Terrahawk CW-20

The integrated LIDAR systems, was designed for the acquisition of LIDAR data with high accuracy (± 5cm RMSE at an average acquisition distance of 100m), supplemented with RGB information for each point. Lidar systems are composed of several subassemblies detailed below:

• System platform, CPU integrator developed by the Phoenix LiDAR Systems for the LIDAR-GPS-IMU assembly, which has the function of correlating in real time the data acquired from all the sensors of the system.

• GPS navigation system: dual frequency RTK-GNSS system, with GPS / GLONASS support. The DJI D-RTK system used for the DJI MATRICE M600 PRO UAV system is partially used. The LiDAR system has its own GPS subassembly composed by two GNSS antennas. This GNSS systems is also used for improving the heading and the alignment of the entire system. This kind of GNSS subsystem is used in correlation with a medium or low accuracy IMU sensor (for example like ADIS sensors). When the system has a precise IMU sensor, it can be used just a single GPS antenna.

• IMU Inertial System - Analog Devices model ADIS 16488 (IMU-14) or STIM (IMU-27), integrated into the system platform (CPU unit)

• VELODYNE VLP-16 PUCK or VELODYNE VLP32C Lidar sensors for acquiring the point cloud.

• PHOTO CAMERA Sony A6000 or Sony A7R II are used to capture RGB colors for each point determined by LIDAR technology. The images thus acquired can also be used for photogrammetric products (photograms, stereo-restitution, orthophoto), if the flight of data retrieval is designed in such way to ensure the necessary coverage of the images (longitudinal, transversal).

Detailed characteristics for all three systems developed are presented in the table 1.

Table 1. System characteristics and performances

LIDAR SYSTEM	**DJI M600 PRO - LIDAR SCOUT 16**	**DJI M600 PRO - ULTRASCOUT 32**	**Terrahawk CW-20 T-ULTRA**
Lidar sensor	Velodyne VLP16 PUCK	Velodyne VLP32-C	Velodyne VLP32-C
Lidar range error	Max. ± 30mm	Max. ± 30mm	Max. ± 30mm
Scan rate	300k pulses/s, 2 returns/ pulse (600k points/s)	600k pulses/s, 2 returns/ pulse (1.2 mil points/s)	600k pulses/s, 2 returns/ pulse (1.2 mil points/s)
No. of Laser Planes	16	32	32
Field of view	30˚vertical 360˚ horizontal	40˚vertical 360˚ horizontal	40˚vertical 110˚ horizontal (CW-20)
Range of scanning	1.0-100 m	1.0-200 m	1.0-200 m
Aerial platform	DJI M600 PRO, Electric engine, 6 Bat.	DJI M600 PRO Electric eng., 6 Bat.	CW-20 Terrahawk VTOL, mixt engine, 4 bat., thermic engine 60cc
Positioning system	DJI D-RTK	DJI D-RTK	CGS D-RTK
IMU	ADIS 16488 (IMU 14)	IMU 27	IMU-27
Weight	9.5 kg	9.5 kg	19 kg (excl. fuel)
Payload	3.5 kg	4 kg	6 kg (incl. 4 l fuel)
UAV dimension	1668mm x 1518mm x 727mm	1668mm x 1518mm x 727mm	3200mm x 1800mm x 190mm
Box dimension	525mm x 480mm x 553mm	525mm x 480mm x 553mm	2180mm x 560mm x 420mm
D-RTK accuracy	Vertical: ±2cm ± 1ppm, Orizontal: ±1 cm ±1ppm	Vertical: ±2cm ± 1ppm, Orizontal: ±1 cm ±1ppm	Vertical: ±2cm ± 1ppm, Orizontal: ±1 cm ±1ppm
Wind resistance	8 m/s (28.8 km/h)	8 m/s (28.8 km/h)	10 m/s (36.0 km/h)
Speed	18m/s (64.8 km/h)	18m/s (64.8 km/h)	25m/s-40m/s (144 km/h)
Lidar accuracy / optimum fly height	55mm RMSE at 40m Recommended AGL 50m	55mm RMSE at 50m Recommended AGL 100m	55mm RMSE at 50m Recommended AGL 100m
Camera	Sony A6000 24 MP	Sony A7R II 42MP	Sony A7R II 42MP
Focal length	15 mm	21 mm	21 mm
Image resolution	7.3 cm at 300m fly height	6.4 cm at 300m fly height	6.4 cm at 300m fly height
Flight time maxim/ with maxim payload	40minutes / 25 minutes	40minutes / 23 minutes	3 hours / 2 hours
Productivity / flight	4-5 ha	4-5 ha	8 – 11 Square km

2.1 LiDAR Systems DJI M600 PRO – Scout 16 and Ultra Scout 32

The D-RTK Rover system from Figure 2 contains two GPS antennas, capable of receiving signals from satellites, both from the NAVSTAR and GLONASS GPS constellations. In the Asia-Pacific area they are programmed to use the signals from the BEIDOU satellites as well. The D-RTK Rover system also contains a satellite data analysis processor, as well as a radio module for receiving basic corrections (DataLINK PRO 900).

Fig. 2. D-RTK component

Fig. 3. LiDAR-IMU-CPU-Camera

The D-RTK Base system is basically similar to the one installed on the drone, except that only one GPS antenna is required for the base and not two. In addition, the radio module is designed to provide corrections, not receive (Figure 2, right). The power supply in the case of the basic D-RTK module is achieved by connecting it to a DJI TB47S type battery, or a similar battery.

The D-RTK system is used for precise flights, inhibiting the functionality of the A3 Pro flight GPS antennas (only for the 3 smaller GPS antennas to determine the navigation position and the course angle, with a lower accuracy). Thus, the DJI MATRICE M600 PRO drone in this configuration can be used for geodetic applications and for scientific research applications where accuracy is a request. The D-RTK GNSS antennas can also be used for improving the accuracy of the IMU sensor (for example on LiDAR Scout 16 system).

The main subassembly of those subsystems is composed by the LiDAR sensor, CPU, IMU and the optical camera which are integrated as is seen in the Figure number 3.

This subassembly is integrated in a single component. This is an absolute condition to obtain a good accuracy of the measured data. All the components are related to the IMU sensor through the measured offsets and the rotation angles between each coordinate system of each component.

2.2 Terrahawk CW-20 with optical camera or LiDAR (Ultra Scout 32)

The Terrahawk CW-20 system can be equipped with one sensor at a time: a DSLR camera (Sony A7R II) or a LiDAR sensor (Velodyne VLP 32c). Because of this reason it is necessary two flights over an area to obtain a cloud point LiDAR with RGB. Even with this inconvenient, the acquisition of a RGB cloud point is much more efficient than hexacopter LiDAR systems.

The function of this system is pretty much the same with the one from DJI M600 PRO system. In figure 4 are presented the main components of this system. The airplane is a VTOL UAV (vertical take-off) with four electrical motors for take-off. This add the advantage of a hexacopter to an airplane and make it more suitable for a lot of missions. Maybe the VTOL is the most important characteristic of CW-20 because it doesn't need any runway. After the airplane climb up about 50 meters, the gas engine is starting, and it goes with high speed (about 100 km/h) on the planned trajectory. Inside the airplane you can easily mount the Camera, which is connected to the airplane autopilot. In this case the IMU of the airplanes the same IMU used by the camera to measure the angle rotations: omega, phi kappa. Also, the system use the same GPS antenna of the airplane for measuring the projection centres of each image captured.

Fig. 4. Components of the Terrahawk CW-20 system

When it is used a LiDAR sensor, this will be mounted inside the fuselage of the airplane using a shock absorber support. The LiDAR sensor come with its own CPU and IMU sensor. The CPU is necessary to compute every single laser measurement in correlation with angles of acquisition, IMU measurement and GPS position. A LiDAR sensor require a more precise IMU sensor, so it can not use the IMU from the airplane. Another reason why it can not be use the airplane sensor is because the IMU must be fixed with the LiDAR sensor to measure the precise movements of this. Concerning the GPS component, in this case, the LiDAR system can use the same GNSS antenna of the airplane.

Another important component is the Ground Control Station GCS 202 (Figure 4, right). This is an integrated GNSS antenna, WiFi modem and radio receiver-transmitter. The role of this component is to assure the connection between the command centre and the airplane. Also, the GCS is used to transmit RTK corrections to the airplane so the airplane would follow the trajectory with a precision of 1 meter. The GCS serve a great role when the airplane has to land. Using the correction provided by the GCS, the airplane can land within a maximum 0.5 meter from the take-off location.

The last component is the command centre which is compound by a performant laptop and the CW Commander Software. The software is used to generate the photogrammetric/LiDAR mission, but also for monitoring and command the airplane in emergency situations (Figure 6). The remote radio controller is used just for testing that all the components are working fine (ailerons, rudder, elevators, throttle, etc.).

3. Applications

3.1 Mapping

One of the main applications tested in this research was the generation of a standard map as it is done using classical measurements with topographic equipment or by classical aerial photogrammetry with large cameras.

First step started with the delimitation of the area to be mapped using the UAV system (figure 5). This was done at the office using Google Earth software. Several measurements were completed to establish details related to the length, width, surface, occupancy of the land, the maximum and minimum height of the objects existing in the area (using street view), trying to identify the possible obstacles that could endanger the fly.

Using the preliminary information, the design of the flight plan for DJI M600 was done in the Mission Planner software (figure 5) and was flight with Fly Litchi software. The flight lines are there designed, the distance between them, the flight height of the DJI drone, the angle of flight, the speed of flight, the working precision, all these parameters were set and then checked on the ground.

Fig. 5. Definition of the working area and planning of the mission

For mapping with CW-20 photogrammetric system it is used just the CW Commander software. CW Commander can calculate the photogrammetric mission very quickly, using almost any camera. To calculate the photogrammetric mission the pilot must parametrize this with the following: the longitudinal and the side coverage, the size of the pixel on the ground (GDS), the ground altitude, the focal length, the size of the optical sensor, the starting point, and the frame of the photogrammetric block. The same software is used for monitoring the parameters of the fight at any moment. This software is presented in figure 6.

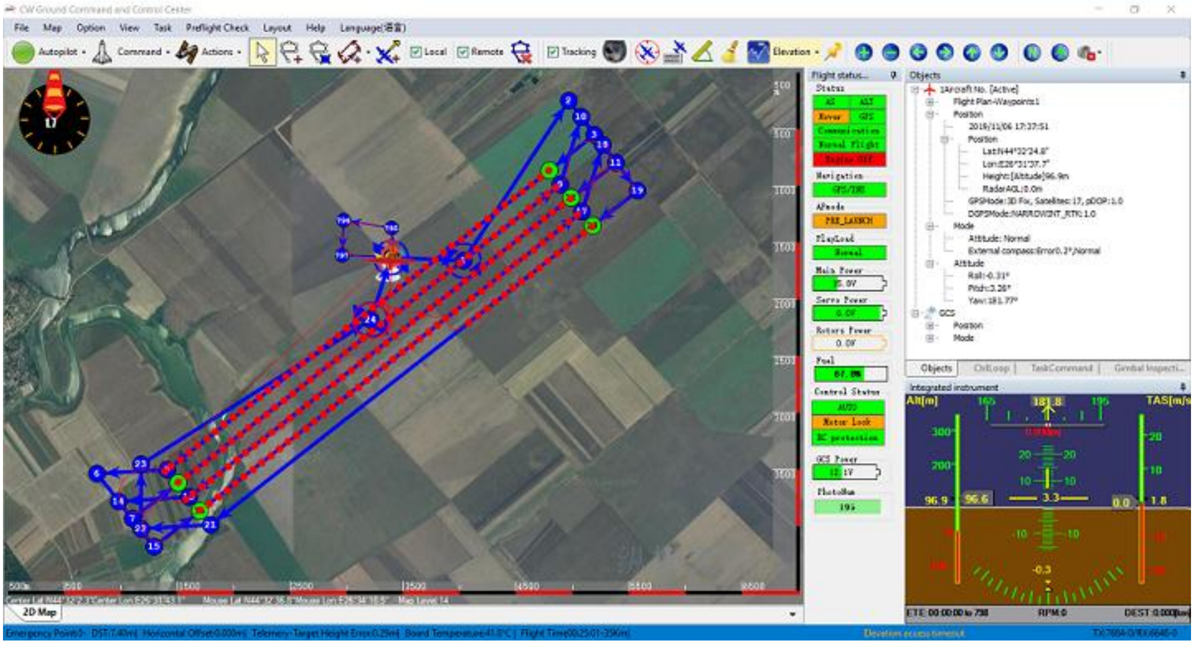


Fig. 6. Flight plan and acquisition of a photogrammetric mission with CW-20

For testing different parameters for fly, three flights were designed from different heights with the DJI M600 VLP 16 LiDAR system (see picture 7).

The first day that flew was when the average temperature was 11ºC, the wind speed was 6km / h, the visibility was 7.6km, the humidity was around 70mmHg. On this first day the flight was made at a flight height of the drone set at 60m, so chosen to have visibility between operators and the drone, but also between the drone and the WIFI long range antenna.

Another flight was made at a flight height of 40m, on a length of 1.6km, with LIDAR and optical data being acquired for objects such as roads, houses, cars, electric poles, high and low vegetation.

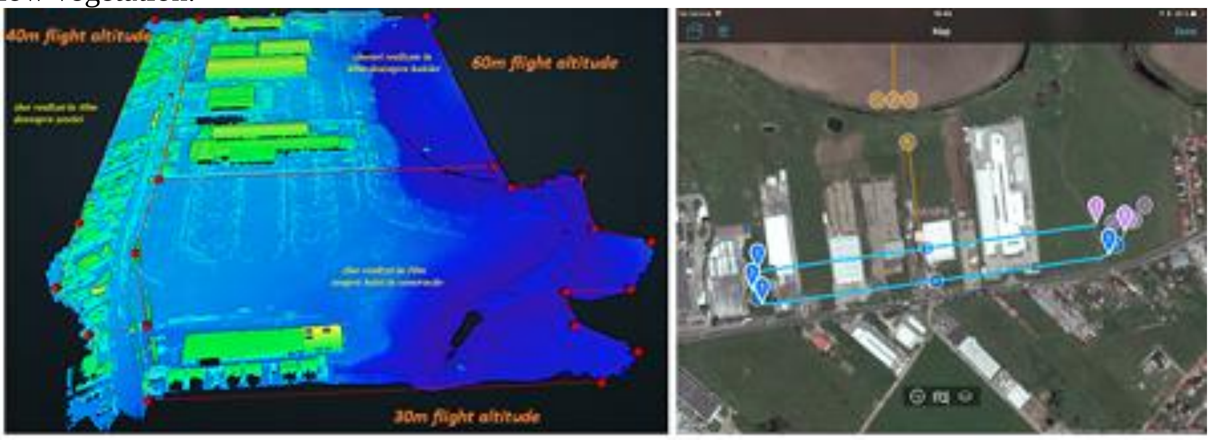


Fig. 7. Distribution of flights (left) and an example of the planned mission (right)

The last flight was carried out in the uncoated part of the Pantelimon Hale area. The flight was made at a flight height of 30m, in order to be able to achieve LIDAR points on the power lines, on the roofs of the buildings located in the east of the analysed area, but also on the hall under construction (objects with high reflectance surfaces).

After the data acquisition and post-processing, the trajectory, the final point cloud was obtained. With the self-developed application LIDAR Tools was generate the DTM and also the DSM as it is exemplified in Figure 8. Finally, the orthorectified images and the orthophoto were obtained for the entire area (Figure 8).

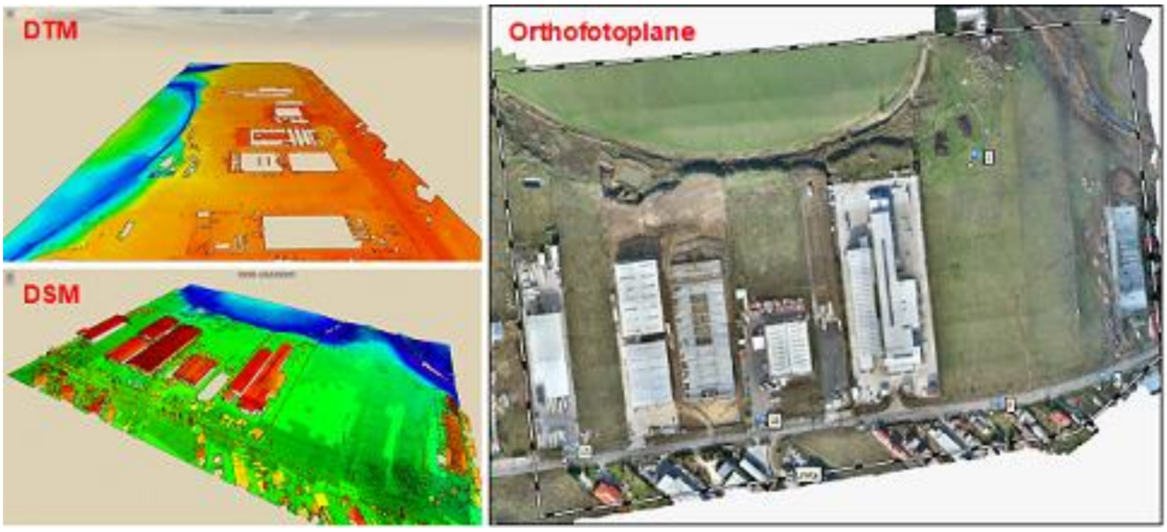


Fig. 8. DTM and DSM from LiDAR point clouds and the generated ortophotoplane

Another mapping product obtained from the UAV LiDAR Optical system was the GIS topographical map. The contour levels was generated on the DTM 3D model. The vectorisation of the entities was done using the orthophotoplane, but also the LiDAR point cloud. All the objects was completed with other geo-structural information in a GIS database. The final result can be seen in Figure 9.

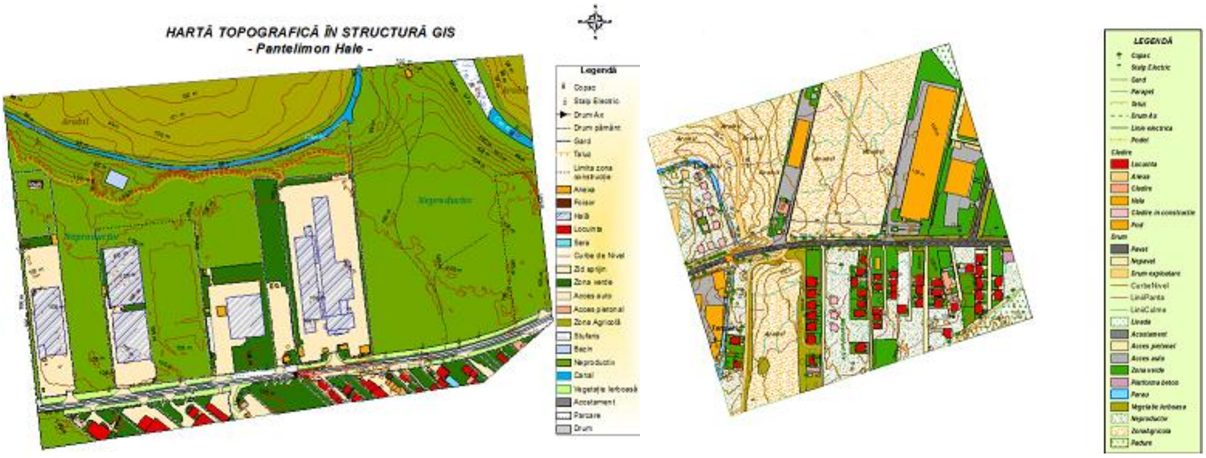


Fig. 9. GIS topographical maps derived from Lidar scanning

3.2 Virtual 3D Modelling

Three-dimensional modelling of the LiDAR point clouds can be made in a classical way (without colours) or in an innovative way (with RGB information). The differences can be observed in the examples from Figure 10.

The main feature of the new concept of 3D modelling is that for every LIDAR point in the whole points cloud we have the RGB information. This feature allows the user to obtain a product that manages to reproduce reality as effectively and naturally as possible.

Another particularity by which the product becomes special is, that this way of obtaining the realistic virtual model allows the realization of various types of measurements on the virtual image, determinations that reflect the real values in the field.

Fig. 10. Virtual 3D modelling without or with RGB information

We develop a web application called Potree-Prosig which is used for 3D modelling of the LiDAR point clouds. The software renders a 3D modelling without making any mesh surface. The principle of this modelling is simple: for every point it is used splats until it meet the next neighbour points. Another 3D representation it is exemplified in Figure 11.

Fig. 11. Virtual 3D modelling using HQ Splats interpolation (Potree-Prosig)

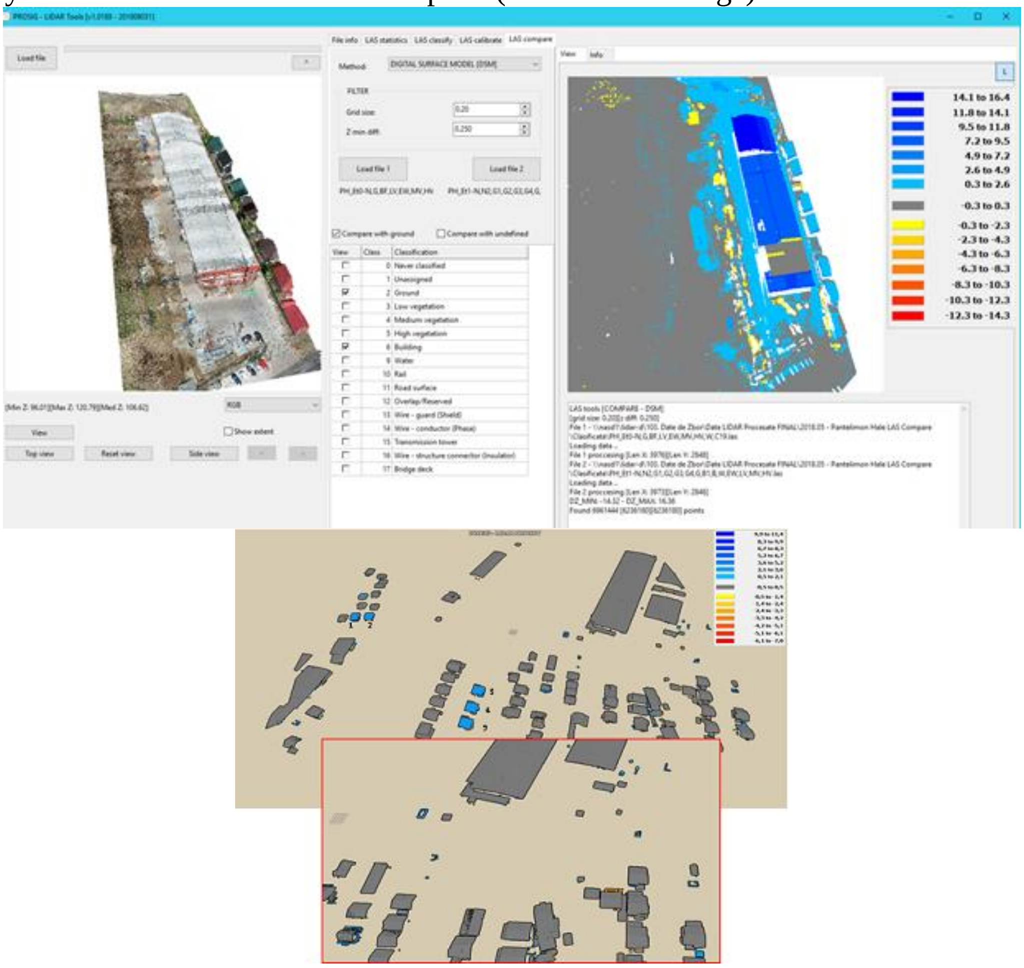
The presented product, the realistic representation of a geographical area, is obtained with an internal accuracy of 5 ÷ 10cm (depending on the flight height of the LIDAR system).

3.3 Change detection

The report on the identification and quantification of landscape change detection (Figure 12) is a new product that seeks to help the user with some comparative information, all centralized and presented as descriptive as possible. These are results obtained from the comparative analyses, performed on the two sets of data, obtained at different times, on an area that is subject to monitoring.

The results that are presented as a new product (report on the identification and quantification of landscape changes), are given for each thematic class: land (dry or water), construction (housing, civil or industrial objectives – see Figure 12), elements of over-ground infrastructure (roads, bridges, railways, electric lines), hydrotechnical installations (dams, shore, consolidations), vegetation (low, medium, high) - depending on the elements identified in the analysed area.

The product is provided in a digital format, delivered by electronic means and contains structured information. The report on the identification and quantification of landscape changes is useful in various areas, but the most obvious are those disasters that cause landscape changes. The report can be successfully used in the event of floods, landslides, even earthquakes. In all these situations, the applicant for the report must provide the service provider descriptive information about affected geographical area. They will be used as auxiliary data measurements taken in step T0 (the reference stage).



Phase	Number of compared points	Number of identified changes	Observations	Conclusions
T_0	73 437 215	- 5 new buildings. - 0 demolished buildings. - 11 new annexes or extensions of existing buildings. - 1 demolished annex.	5 new buildings, consisting of up to 3.6 meters. The differences found in the annexed constructions are not high.	The new buildings are houses or a new floor of a building.
T_1	73 585 762			

Fig. 12. Results of the PROSIG application Lidar Tools, Change detection function

Obtaining this product is based on the principle of identifying and quantifying landscape changes using LIDAR points clouds (or photogrammetric point clouds – tie points generated on images). The method can be successfully applied on classified or unclassified points cloud. In order to achieve high precision results, at least the noise and ground points must be extracted from both data sets.

To achieve this report, we used the self-developed application LIDAR Tools. This it is also used for LiDAR data processing. For viewing, analysing, and quantifying landscape changes we used the Potree-Prosig web application, also a self-developed application.

The presented report on identifying and quantifying the landscape changes, is obtained with an internal accuracy of 5 ÷ 10 cm (depending on the flight height of the LIDAR system) and an absolute accuracy of 10 ÷ 15 cm. The points cloud density, which are used to prepare this report, can be parameterized by the operator.

4. Conclusions

It is necessary here to underline the importance of the new developed photogrammetric and lidar technology based on drones. This kind of systems makes it affordable the use of lidar and photogrammetric technologies to small areas, inaccessible areas with classical topographic equipment. Also, this kind of approach allow the user to model different kind of objects at an accuracy not accessible with the manned planes. On the other hand, for small areas in accidental areas the hexacopter can be easier used. The fix wing system is not adapted for mountain areas with high differences in altitude. This system is recommended to be used on areas with slow altitude differences that the aircraft can track at an average altitude.

Another conclusion is the high efficiency of a VTOL UAV in a photogrammetric mission (Figure 13), but also in a LiDAR mission. Thus, in case of needing a 3D accurate realistic modelling, a scanning realised with CW-20 is not well suitable. In this case, we recommend a hexacopter for better and complete results because of the lower speed.

Concerning the LiDAR accuracy, it is obligatory to emphasize the importance of a precise IMU sensor.

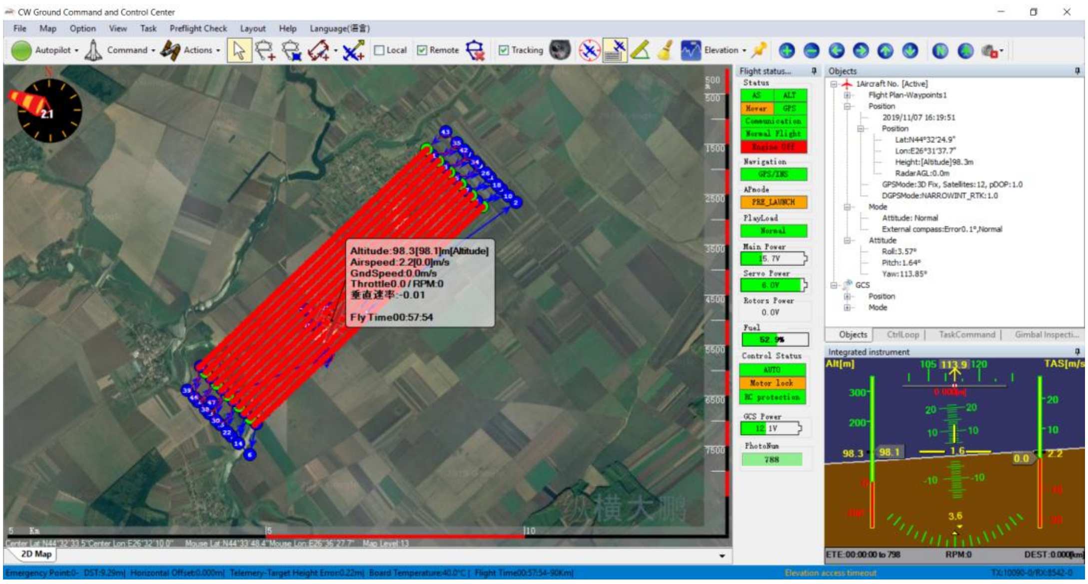


Fig. 13. One photogrammetric mission of 15 square km

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