DOI: 10.24427/978-83-66391-62-8_7

7. ADVANCED TECHNOLOGIES IN AERIAL MAPPING

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Aerial mapping is one of the most advanced methods to obtain information about the surface of the Earth and other objects using remote sensing technology. The quality of cartographic products and 3D models mainly depends on the success of aerial photography/ scanning mission, qualified guidance of photogrammetric workflow, appropriate realization of aerial mapping requirements.

7.1. Concept of Remote Sensing

Remote Sensing (RS) is defined as the acquisition and analysis of remotely sensed images to gain information about the state and condition of an object through sensors that are not in physical contact with it and discover relevant knowledge for decision making. Remote sensing for environmental monitoring and Earth observations can be defined as: it is the art and science of obtaining information about the surface or subsurface of the Earth without needing to be in contact with it. This can be achieved by sensing and recording emitted or reflected energy toward processing, analyzing, and interpreting the retrieved information (Chang, Bai, 2018)

Remote sensing technology is used for the mapping of the Earth's surface and objects. Data are obtained from different sensors arranged at different platforms (unmanned aerial vehicles, airplanes, spacecraft and satellites, ships and submarines), ground stations, without touching the objects to be mapped. The usage of different platforms has its own advantages and disadvantages (Tab. 7.1).

In capturing imagery in remote sensing, the following factors should be considered: flight restrictions, image resolution and coverage. Sensors, equipped at satellites, capture data at a global scale, unmanned aerial vehicles better to use for flying over small areas, airplanes and helicopters take the middle position.

TABLE 7.1. Evaluation the usage of different platforms (Source: WEB-1)

Platforms	Unmanned aerial vehicles (UAVs)	Airplanes and helicopters	Low Earth orbit satellites
Advantages	Very high-resolution imagery programmable flight paths; LiDAR capabilities.	High resolution imagery; pilot-flown flight paths; LiDAR capabilities.	High to coarse resolution imagery; large coverage extent.
Disadvantages	Very small coverage extent; visual line of sight.	Small coverage extent; flight operation.	Coverage limited to orbital path; cloud obstructions.

Types of remote sensing and their some features are presented in Figure 7.1.

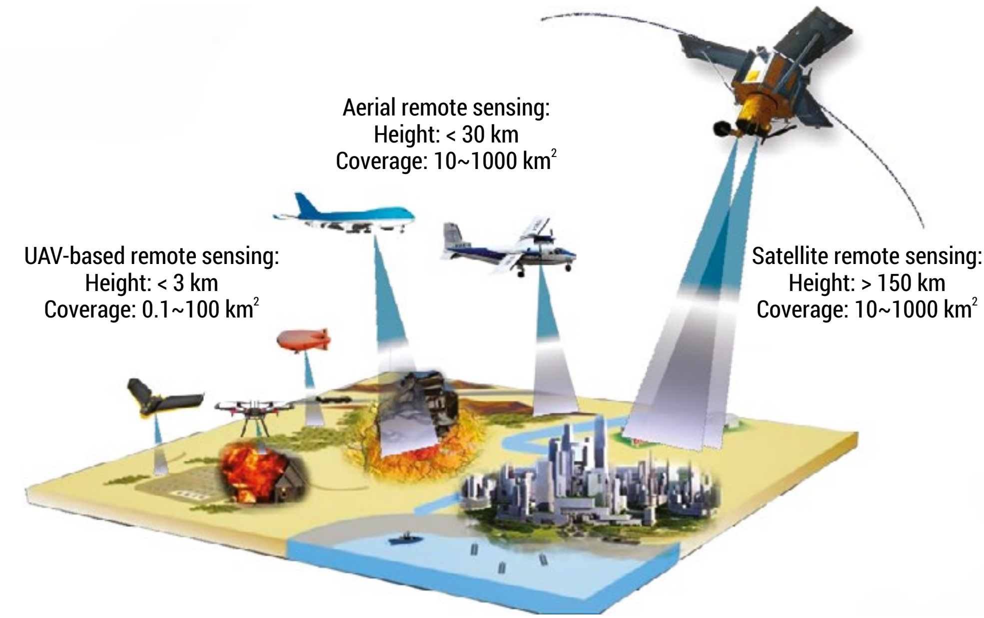

FIG. 7.1. Types of remote sensing/ platforms (satellite, manned aviation and low-altitude UAV) (Source: Xiang, Xia, Zhang, 2019)

Two types of sensors are used in remote sensing:

1. Passive, when photographing with optical photography systems – electromagnetic energy reflected or radiated from the Earth's surface is collected. This method involves the production of an aerial photograph.
2. Active, when electromagnetic energy is generated in the system itself. The Earth's surface is scanned with radar (RADAR – Radio Detection and Ranging, IFSAR – Interferometric Synthetic Aperture Radar) or laser (LiDAR – Light Detection and Ranging) systems (Ruzgiene, 2008).

Figure 7.2 shows principle of passive and active sensors, equipped at unmanned aerial vehicle, operation.

FIG. 7.2. **Principle of passive and active sensors operation (Source: WEB-2)**

Data from remote sensing are used for: the construction of small-scale topographic and thematic (geological, tectonic, geobotanical, landscape, etc.) maps; updating the cartographic material; mapping of rapidly changing objects (for example, agricultural land, minerals, cities, roads and hydraulic equipment, construction sites); mapping under-explored and hard-to-reach areas; creating operational maps; monitoring the dynamics of various processes and phenomena; determining the type of crop, crop area or condition; monitoring the growth process of agricultural land, forecasting the yield; determining the thickness of snow cover in large areas; studying the seasonal movement of ice in the oceans, etc.

Remote sensing technology continues to be developing and improving, with the appearance of more uses and opportunities to create value in new industries and fields of study – from environmental science to public safety, to telecommunications. Several different remote sensing methods are available today, and each comes with strengths and limitations.

The most popular remote sensing type is UAV-based remote sensing with application of UAV-Photogrammetry and Light Detection and Ranging (LiDAR) technologies.

7.2. Remote sensing with Unmanned Aerial System

The use of the Unmanned Aerial System (UAS) for the mapping of objects with varied form of topography leads to a new level of surveying technology. UAS defined as Aerial Imaging solution is designed for the reduction of time and cost collecting aerial cartography data as well guarantees the reliability of mapping products.

The typical components of the mobile segments are as follows (Armenakis, Patias, 2019):

- the vehicle platform (UAV), which enables motion and houses the engine and all other systems;
- the navigation module, which guides and controls the motion of the platform and includes the onboard, autopilot, global navigation satellite system (GNSS), inertial measurement unit (IMU), altimeter, compass and navigation cameras;
- telecommunication links (command and control, downlink telemetry and sensor data);
- the propulsion system and power generation system, including batteries and fuel tank;
- mapping sensors (still/video optical cameras, thermal, multispectral and environmental sensors, and laser scanners).

7.2.1. Substantial features of UAS

The past few decades have witnessed great progress for Unmanned Aerial Vehicles (UAVs) in civilian fields, especially in remote sensing and photogrammetry. In contrast with manned aircraft and satellites, platforms flying at low altitude have many promising characteristics: flexibility, efficiency, high spatial/ temporal resolution, low cost, easy operation, and so forth, that make them an effective complement to the other remote sensing platforms and a cost-effective means for remote sensing.

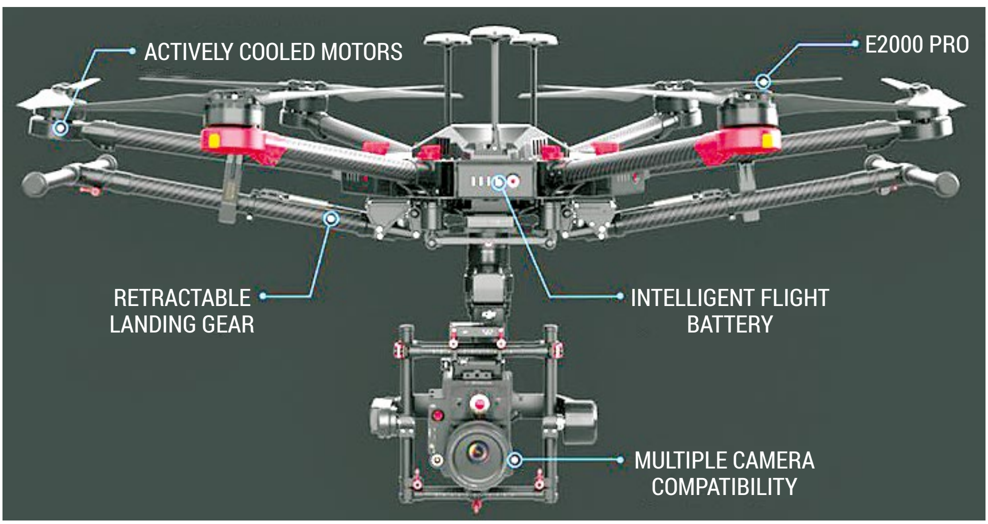

FIG. 7.3. Basic components of UAV (Source: WEB-3)

Unmanned aerial vehicles of different models, classification and categories can be used for aerial mapping, for example, helicopters with four or six wheels, the fixed-wing *UX5* from the company Trimble, etc. The company Dà-Jiāng Innovations (DJI), China, rapidly turns to a new standard in mapping of territories combining a robust and highly user-friendly system. The standard technical means from DJI used for surface data acquisition are: the platform *MATRICE 600 PRO* with a custom-designed camera *ZENMUSE X5*, thermal camera *ZENMUSE XT*, laser scanner *MAPPER LITE 2*, GPNS. The *MATRICE 600 PRO* is a hexa-copter specifically designed for professional and industrial applications. It features an enhanced flight performance with the capability to carry a heavier payload. The vehicle also comes with pre-installed arms and antennas that reduce set up time. The *MATRICE 600 PRO* features six rotors for added redundancy and stability in the air. The vehicle also features six batteries for added safety and an extended flight time. Basic components of UAV are presented in Figure 7.3.

Main features of DJI *MATRICE 600 PRO*:

- Weight (with six TB47S batteries) – 9,5 kg.
- Max wind resistance – 8 m/s.
- Max speed – 65 km/h.
- Hovering accuracy (P-GPS) – vertical: ±0,5 m, horizontal: ±1,5 m.
- Hovering time (with six TB47S batteries and scanning equipment) – 32–35 min.
- Max service ceiling above sea level – up to 2500 m.
- Max takeoff weight – up to 15,5 kg.
- Operating temperature – –10°C to 40°C.

The gimbal light camera *ZENMUSE X5* mounted at DJI *MATRICE 600 PRO* can be successfully used for the photogrammetric data acquisition. The main features of the camera *ZENMUSE X5* is presented in Figure 7.4.

Sensor:
Size – 17,3 × 13,0 mm
Type – CMOS
(complementary metal-oxide semiconductor)
Pixels – 16 M
Resolution – 4608 × 3456 px
Optics:
Focal length – 15 mm / 30 mm
Video:
Resolution – 4096 × 2160 px
Format – MP4 / MOV

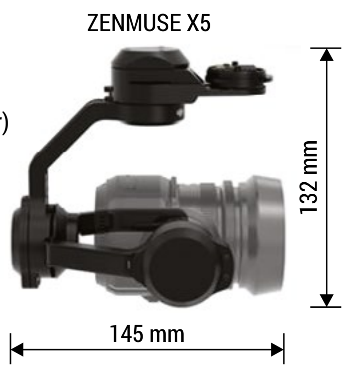

FIG. 7.4. Main features of gimbal camera *ZENMUSE X5* (Source: WEB-3)

A 3D laser scanning system of special type can be mounted quickly on any UAV when the requirement is the use of LiDAR (Light Detection and Ranging) technology. One of the most popular laser scanners is *YellowScan MAPPER LITE 2*, that has an easy-to-handle, easy-to-use and accurate system. This scanner is fully autonomous, has direct georeferencing workflow for increased accuracy and efficiency of mapping from UAVs. The main features of laser scanner *YellowScan MAPPER LITE 2* is presented in Figure 7.5.

MAPPER LITE 2

Weight – up to 2,2 kg
Navigation systems:
GPS, GLONASS, Beidou, Galileo1, SBAS
Optimal scanning height – 10-75 m
Scanning precision – 10 cm (XY), 5 cm (Z)
Shots per second – 18500
Laser scanning technology – up to 3 echoes per shot

FIG. 7.5. Main features of laser scanner *MAPPER LITE 2* (Source: WEB-2)

The 3D laser scanning system is fueled by the needs of surveyors, researchers, asset managers and all people requiring LiDAR data.

7.2.2. UAV-Photogrammetry

The modern technology of UAV-Photogrammetry is used for remote sensing of surfaces, acquiring a huge number of images and processing of the photogrammetric data. Photogrammetry is one of the most advanced methods to acquire information about the surface of the Earth and other objects using photographic images. The use of unmanned aerial vehicles (UAVs) with the integrated camera for image capturing, GPNS, the management equipment and specialized software for the processing of images has been rapidly expanding for aerial mapping. The orthophoto maps of high accuracy (quality) and three-dimensional surface models are the main products generated by the use of aerial photogrammetric technology.

The UAV-Photogrammetry technology contains the use of UAV with integrated photographic equipment for gaining images of surfaces, flight planning and control, photographic image processing by specialized software.

A typical workflow for the use of UAV-Photogrammetry technology is presented in Figure 7.6. Main steps are: mission planning → image acquisition → UAV image processing (triangulation and DTM/ DSM generation).

The image data processing software *Pix4Dcapture* and *Pix4Dmapper* developed at Computer Vision Lab in Switzerland is the main tool for the application of modern technologies with the use of UAV. *Pix4Dcapture* is the flight planning and image acquisition module involved in the software *Pix4D*.

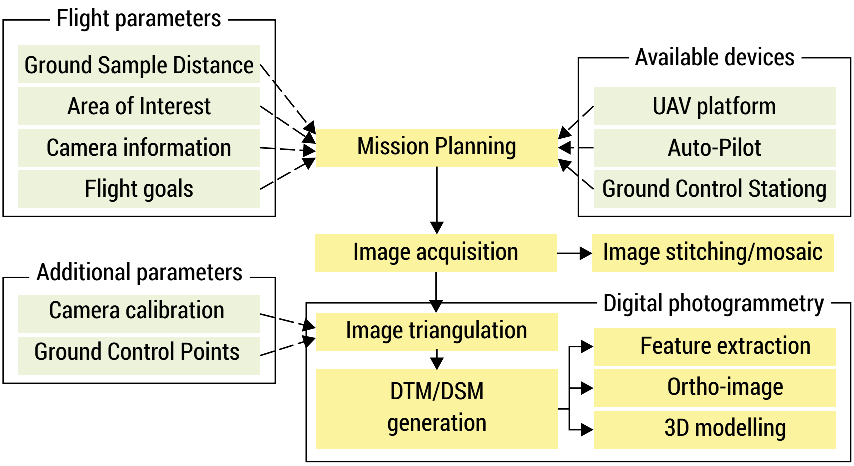

FIG. 7.6. **Typical workflow applying the UAV-Photogrammetry technology (Source: Nex, Remondino, 2014)**

Pix4Dmapper is an image processing software that is based on automatically finding thousands of common points between images. Each characteristic point found in an image is called a *keypoint*. When 2 *keypoints* on 2 different images are found to be the same, they are *matched keypoints*. Each group of correctly *matched keypoints* will generate one 3D point. When there is high overlap between 2 images, the common area captured is larger and more *keypoints* can be matched together. The more keypoints there are, the more accurately 3D points can be computed. Therefore, the main rule is to maintain a high overlap between the images.

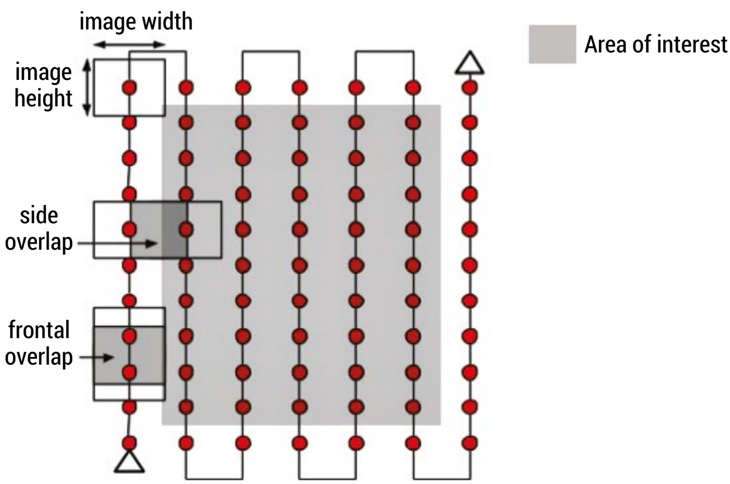

FIG. 7.7. **Ideal image acquisition plan – general case (Source: WEB-4)**

As the image acquisition plan has a high impact on the quality of the results, it is important to design it carefully. The recommended overlap for most cases is at least **75% frontal overlap** (with respect to the flight direction) and at least **60% side overlap** (between flying tracks). It is recommended to take the images with a regular grid pattern (Fig. 7.7). The camera should be maintained as much as possible at a **constant height** over the terrain/ object to ensure the desired ground sample distance (GSD).

The module *Pix4Dcapture* offers the possibility to fly four different kinds of autopilot missions and one manual but semi-automatic mission (Fig. 7.8). To get the best results out of the image acquisition plan, the type of mission has to be chosen depending on the terrain/ objects that need to be reconstructed.

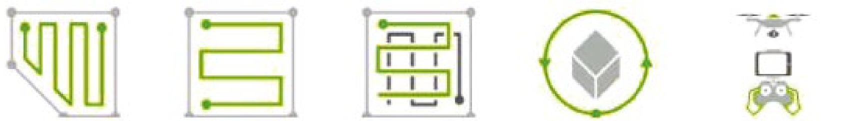

FIG. 7.8. Different kind of autopilot missions (Source: WEB-4)

In an aerial mapping survey, are using ground control points (GCPs) are used which the surveyor can precisely pinpoint: with a handful of known coordinates, it is possible to accurately map large areas. A GCP is a point of known coordinates in the area of interest. Its coordinates can be measured using traditional surveying methods measuring with GPS or total stations; obtaining by other sources (LiDAR, older maps of the area, web map service, even from Google Earth application). Ground control points can be anything that can be easily recognized in the images. Typically, they look like a small section of a checkerboard. The shape leaves very little ambiguity about where the 'point' of a ground control point is. They're almost always black and white because it is easier to recognize high contrast patterns. In order to obtain more precise aerial mapping products, the points/ targets are distributed in a specific order: projecting points at the edges of an object considering configuration, but not so close to the margins because they will not be seen in several images; one point in territory center, as well as points in the areas of a complicated relief (Fig. 7.9). Recommendation for GCPs number – 5 points, minimum – 3, usually – 5–10. Each of GCPs should be seen in 2 images as a minimum, if relief is complicated – 5 GCPs should be seen in 5 images.

The *Pix4Dmapper* software is supplied with computer-vision algorithms combined with proven state-of-the-art photogrammetric techniques to produce outputs with the highest accuracy and with minimal manual interaction. This software is a new concept extending the stereo view triangulation and increasing the accuracy of 3D modelling. Aerial images are imported in consideration with their locations, orientations, and camera calibrations parameters. The use of photogrammetric algorithms allows correction of the image orientations. The software at first performs the adjustment with photo tie points, automatically matching the tie points in all images. Tie points are usually distributed densely, even in low terrain texture. *Pix4Dmapper* software has efficient possibilities for orthophoto generation, surface modelling, etc. Operations with this package are fully automated and flexible, data input is scalable, output data are easily editable and on-site quality assessment is instant.

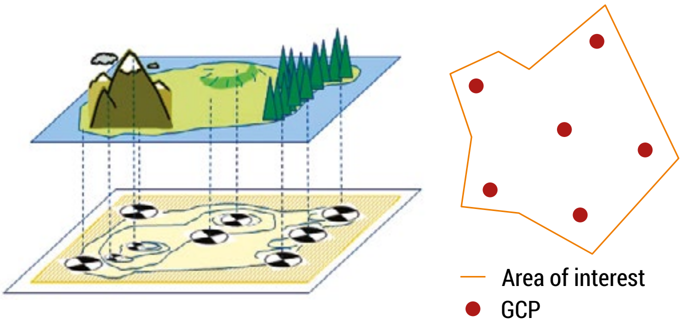

FIG. 7.9. **GCPs and their typical distribution (Source: WEB-4)**

Using different platforms and sensors for capturing the images, the main photogrammetric procedures remain as follows: aerial triangulation, images orientation, generation of point cloud for surface modelling, production of orthophoto map and vector data collection for GIS or cartographic needs. The relation between images and object coordinates can be establish, when the coordinates of ground control points are determined.

Figure 7.10 shows aerial mapping products generated by the use of UAV-Photogrammetry technology; image processing has been performed with software *Pix4Dmapper*.

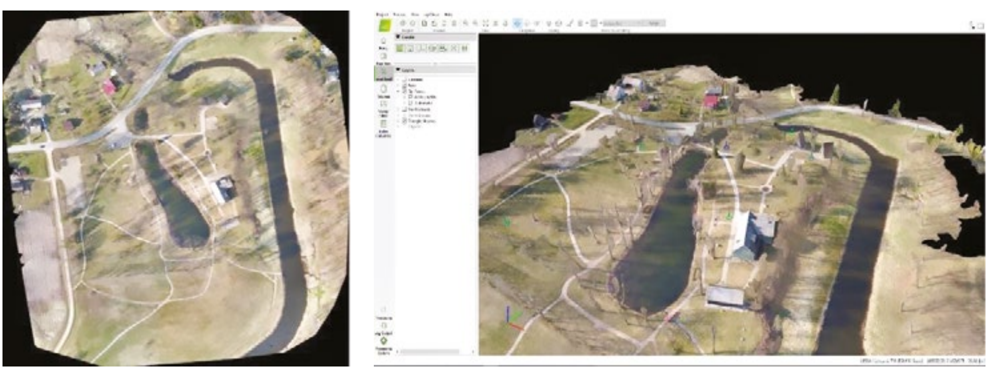

FIG. 7.10. **Aerial mapping products: orthophoto map and DSM (Source: own elaboration, 2020)**

7.3. Remote sensing with laser systems: LiDAR technology

LiDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses, combined with other data recorded by the airborne system, generate precise, three-dimensional information about the shape of the Earth and its surface characteristics (WEB-5). Pulses of light are emitted from a laser scanner, and when the pulse hits a target, a portion of its photons are reflected back to the scanner. Because the location of the scanner, the directionality of the pulse, and the time between pulse emission and return are known, the 3D location (XYZ coordinates) from which the pulse reflected is calculable. The laser emits millions of such pulses, and records from whence they reflect producing a highly precise 3D point cloud (model) which can be used to estimate the 3D structure of the target area.

A LiDAR instrument principally consists of a laser, a scanner, and a specialized GPS receiver. Airplanes and helicopters are the most commonly used platforms for acquiring LiDAR data over broad areas. Two types of LiDAR are: topographic and bathymetric. Topographic LiDAR typically uses a near-infrared laser to map the land, while bathymetric LiDAR uses water-penetrating green light to also measure seafloor and riverbed elevations.

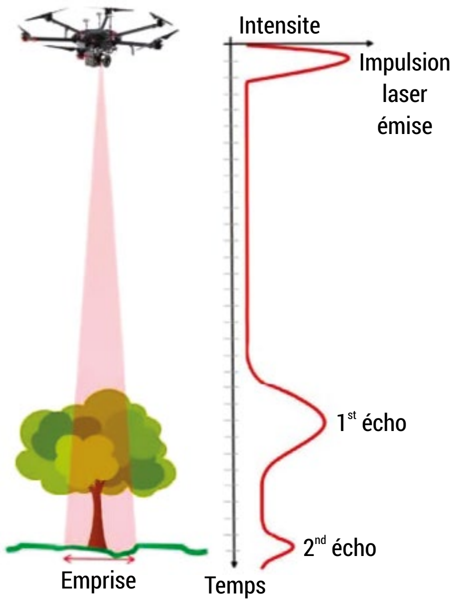

FIG. 7.11. Principle of LiDAR operation (Source: WEB-2)

The principle of LiDAR operations (Fig. 7.11):
1. Emitting a laser pulse on a surface;
2. Catching the reflected laser back to the LiDAR pulse source with sensors;
3. Measuring the time laser travelled;
4. Calculating the distance from source with the formula:
   Distance = (Speed of light × Time elapsed) / 2.

The equipment needed to measure a million distances from sensors to surface points is installed in a LiDAR system. This advanced-technology operates really fast as it is able to calculate the distance between LiDAR sensors and target. LiDAR systems integrate 5 main components whether they are used on automotive, aircrafts or unmanned aerial vehicles:
1. Flying vehicle.
2. Scanning laser emitter-receiver unit.
3. Differentially-corrected GPS.
4. Inertial measurement unit (IMU).
5. Computer.

LiDAR systems pulse a laser light from various mobile systems (automobiles, airplanes, unmanned aerial vehicles) through air and vegetation (aerial laser) and even water (bathymetric laser). A scanner receives the light back (echoes), measuring distances and angles. The scanning speed influences the number of points and echoes that are measured by a LiDAR system. The choice of optic and scanner influences greatly the resolution and the range in which you can operate the LiDAR system.

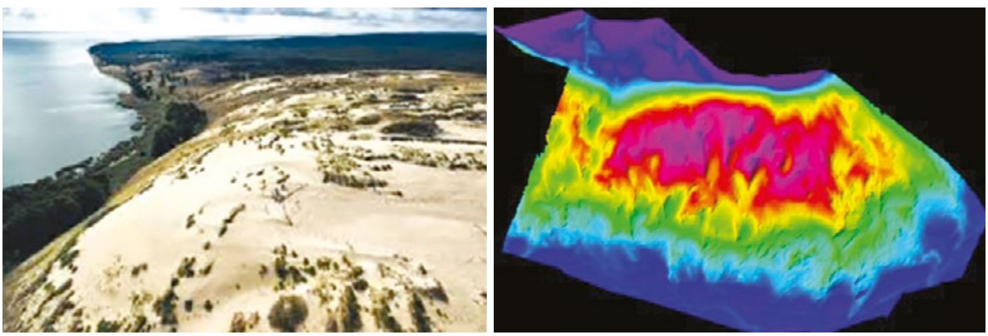

FIG. 7.12. **3D model generated from LiDAR data (Source: own elaboration, 2020)**

Whether a LiDAR sensor is mounted on an aircraft, car or UAV (Unmanned Aerial Vehicle), it is crucial to determine the absolute position and orientation of the sensor to make sure data captured are useable data. Global Navigation Satellite Systems (GNSS) provide accurate geographical information regarding the position of the sensor (latitude, longitude, height) and an Inertial Measurement Unit (IMU) defines at this location the precise orientation of the sensor (pitch, roll, yaw). Data recorded by these devices are then used to generate data into static points: the basis of the 3D mapping point cloud.

In order to collect the data, computation is required to prepare the LiDAR system to work by defining precise echo position. It is required for on-flight data visualization or data post-processing as well to increase precision and accuracy delivered in the 3D mapping point cloud.

LiDAR data – acquired dense point cloud can be processed using the software *MicroStation*, Bentley. This software is an innovative and integral technology of today providing possibilities for 3D surface modelling. Properly generating a digital surface model, it is necessary to add the *TerraScan* and *TerraMatch* toolbars (WEB-6). Figure 7.12 shows 3D models of a surface, generated from LiDAR data.

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