Application of laser technologies in remote sensing of forest areas

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Abstract. The article presents two methods of laser technologies application in remote sensing of forest areas: holographic synthesis of stereoscopic image based on remote sensing data and airborne laser scanning. Both methods are required to obtain data for forest inventory calculating.

1. Introduction

Modern methods of data processing with the help of software and metric packages Pix4Dmapper (Switzerland), Geoscan Photoscan (Russia), Autodesk123DCatch (USA) with its increasing importance have a problem that is not so easy to eliminate by standard solutions in the near future. Automatic orthophotoplanstitching can meet customer requirements and regulatory technical documentation. According to user estimates, the Russian «Photoscan» is leading.

These software packages are used to reconstruct the human body in addition to the construction of 3D polygon objects. For example, the belated PR-action of Autodesk products for the production of a bust of the President of the United States. The media, without full information, declare: «A special installation of 50 exclusive LED lights and 14 video cameras was installed at the White House. «This is not a work of art, but millions and millions of measurements that create an exact copy of the president's figure», said Adam Metallo, a fellow at the Smithsonian Institution. He emphasized that such accuracy was achieved for the first time when copying a real object».

Schoolchildren were engaged in similar things but in color performance in the framework of the Congress of Young Scientists at ITMO University and Saint Petersburg State Forest Technical University.

It is easier to make expert opinions based on a comparison of such an object as the Naval St. Nicholas Cathedral (Kronstadt) surrounded by trees, and not a bust of Barack Obama. Then even a non-specialist will understand everything at a glance. The thinnest tree branches are displayed in high resolution [1].

Nevertheless, all software packages have one big drawback, which does not give them a high-quality performance of three-dimensional models created based on remote sensing data obtained, for
example, from UAVs. The reasons lie in the mathematical methods of triangulation, which underlie the three-dimensional reconstruction of areal and point objects. They work up to a certain point. After which they cannot cope with the interference and stop working with the required quality.

There are many ways to register and reproduce a 3D image:
1. integral Lipman photograph;
2. raster stereo photography;
3. stereopair;
4. hologram;
5. multiplex hologram.

To obtain a planned and perspective woodland geoscene, we use multiplex holography, synthesized from a sequential series of photographic angles taken with the UAV. Classic raster photography has a rather shallow depth and low resolution of scene details. This is due to the limitation of the print resolution and the difficulty of aligning the print on paper with the lenticular raster.

A hologram is the most informative method of optical recording, which has a number of unique optical properties inherent rather to elements of geometric optics - lenses, lens raster and mirrors [1].

A hologram is able to reproduce a wavefront of the most bizarre shape, simultaneously several superimposed three-dimensional images, with its help you can plan the scene space by moving its elements relative to the display plane. This method we put into the processing of remote sensing data using unattended vehicle (UAV) [2].

Another objective was to perform aerial photography and airborne laser scanning of 2 areas. 1 section (red, 4327.7 km²) with a point density of at least 1 point per 1 m², 2 an area (yellow, 440.8 km²) with a point density of at least 4 points per 1 m², 1 section - 4327.7 km², section 2 - 440.8 km² (figure 1).

![Figure 1. Areas to be laser scanned.](image)

In the first example we use laser technology to process remote sensing data, then in the second we will directly use the laser to scan forest areas. Both methods are required to obtain data for forest inventory calculating.

2. Methods and Materials
The method of holographic synthesis of stereoscopic image is very similar to the method of raster photography (figure 2). Separate stereo perspectives (2i) are sequentially recorded on the holographic photographic plate through a narrow slit (1) frame by frame. It is best to use a high-resolution
monochrome LCD matrix with a Fresnel lens (3) and an image diagonal of about 19 inches as a transparency displaying a separate angle.

![Figure 2. The method of holographic synthesis of stereoscopic image description.](image)

First, it will allow the use of digital technology, starting from recording a parallaxogram using a digital camera or video camera, to synthesizing a multi-angle hologram from an LCD matrix. Secondly, the control computer can automate the process as much as possible and eliminate errors when recording 100 - 300 angles.

The design of the installation for recording a multiplex holographic matrix will consist of a diaphragm holder in the form of a narrow slit (1), a movable unit with a photographic plate (2), an LCD matrix for synthesizing images of a sequence of views (3), a fixed unit of Fresnel lenses that focus the laser light on the slit aperture and platform guide (5) (figure 3).

![Figure 3. The design of the installation for recording a multiplex holographic matrix.](image)

The movable unit with a photographic plate and an LCD matrix, after registering each angle, moves along the guides at a distance equal to the width of the slit, while practically all the luminous flux of laser radiation modulated by the LCD matrix is collected at a narrow aperture of the diaphragm. The flat reference wavefront is formed using cylindrical optics and has a cross section close to the aperturestrip diaphragm, limiting the area of the photographic plate when recording each angle.
Such a scheme allows the use of low-power (20 mW) lasers when recording relatively large holograms (about 200x300 mm).

Were used:
1. laser power with a wavelength of 530 nm - 20 mW,
2. slit aperture - 2x200 mm,
3. sensitivity of the photographic plate - 0.5 J / m².

The exposure of one strip will be - 0.2 sec (considering the radiation losses in the optical scheme of the order of 15%).

Using the "Maltese cross" in the drive of the screw pair for moving the photoplate - LCD matrix and oil damping of the moving block, synthesis from 150 angles can be done in two and a half minutes. It is desirable to copy the multiplex matrix with an optical reduction of 1: 2 scale, in which case the pixel structure of the focused image of the observed angles becomes absolutely invisible to the eye. However, in this case, one should not forget about the correction of the size of the synthesized stereo base in order to preserve harmonious proportions of a three-dimensional scene [3].

There will be no disruptions in the synchronization of angles during the reduction of the scale since here all the copied images are flat and when scaling remains aligned even when using spherical optics. This fact allows you to easily synthesize a stereo display and color, as in their synthesis image color separation angle in the process of copying remain consistent.

After recording a "strip" hologram, it is necessary to copy it. The image should be copied using the holographic method onto another photographic plate. During copying, the photographic emulsion should be located in the place where the LCD monitor was during the synthesis. As a result of the copying process, all images of the scene will be recorded in the plane of the emulsion, which is equivalent to the result of registering a focused image of all component angles at the same time. Thus, a reflective master hologram is prepared for subsequent circulation [4].

The feeling of the depth of the displayed space is caused by the fact that within the aperture of the holographic display the viewer sees the image of the foreshortenings through a continuous row of narrow slits. Through each image of the slit, localized at some distance from the hologram, we see only one angle. At the same time, each eye captures an image that is adequate to the observation conditions of real space [5]. Consequently, each observer will have a sense of depth and volume (figure 4).

![Figure 4](image)

**Figure 4.** A scheme of sequential synthesis of stereo images from Fourier spectra.

The described method is not the only one. But its performance is unparalleled among others, such as those where Fourier-spectra are recorded, synthesized by numerical methods from a sequence of photographic angles. (Time savings are made by reducing the number of consecutively recorded items equal to the number of angles.) But for the Fourier method there is almost no limit in the size of the
holographic display. In the case of computer synthesis of a three-dimensional scene, vertical parallax is quite simple. It should be noted that the Fourier-synthesis method is one-step and does not require subsequent copying to obtain a focused image of the angles.

The disadvantages of the first method can be attributed only to the absence of vertical parallax. But the same disadvantage turns into dignity - to restore such holograms do not require high-quality point lights, while the sense of depth and volume remains for the viewer almost the same.

The principle of airborne laser scanning is quite simple. A carrier with a laser-location equipment installed on it flies over the forest, which scans the indicated territory. At the same time, aerial photography of the territory can be carried out from the same board.

The laser beam, penetrating through the forest canopy to the ground, is reflected from various layers of woody vegetation with a certain density.

The technology works based on the phenomenon of light reflection and scattering in transparent and translucent media. The laser scanner generates up to 500 thousand pulses per second. Each pulse can give several reflections from the scanned surface, which are recorded by the receiver of the scanner installed on board the aircraft. The measurement results are so-called "point clouds"[6].

After scanning, each point in the cloud is assigned its own class: land, vegetation, buildings, noise, water surfaces, and so on, depending on the tasks to be solved.

Due to the high accuracy of measurements, high-precision digital models of relief, terrain and forest canopy are formed from the data obtained. These digital models make it possible to automate the processes of their processing, as a result of which there is no need for routine and rather lengthy image processing, which is typical for classical photogrammetric methods of image processing.

Planning aerial photography and airborne lidar scanning: a calibration flight was carried out before work began (figure 5).

![Figure 5. Planning aerial photography and airborne lidar scanning.](image)

### 3. Results and Discussion

After describing the methodology for recording a multiplex hologram in a ground laboratory environment, one can understand the simplicity and complexity of our experiment, which we successfully carried out using an aircraft in the field. This is the fundamental difference between our technology and technology, which is covered in the open press by foreign colleagues. We work with “live material”, not synthesized artificial digital data. Our basic principles coincide with those described above in the laboratory. The use of an unmanned aerial robot for this purpose was the first in the world.

From June 27 to December 25, 2020, the initiative group of Saint Petersburg State Forest Technical University and ITMO University conducted aerial photography of forests. After secondary processing of remote sensing data, a monochrome multiplex hologram was recorded.

Aerial photography is the first stage of the experiment, the ultimate goal of which was to create a multiplex hologram. The survey was carried out from a multi-rotor UAV in automatic mode along pre-
designed routes. To build routes for flying around the forest, a ground control station module was used, which allows you to build routes along the outer boundaries and heights of trees. During the flights, planned and circular aerial photography of the woodland was carried out with a resolution of 0.5-1 cm per pixel and more than 750 photographs were obtained. At the same time, high-precision positioning was ensured [7].

For the first time, aerial photography was carried out from heights of up to 80 meters, while the outer height of the trees was 70.5 meters (figure 6).

Figure 6. The process of creating a 3D model based on aerial photographs.

The specialists of Institute of Telecommunications, CJSC and ITMO University processed aerial photography data with the formation of input data for the final third stage - their transformation into a multiplex hologram.

Airborne laser scanning was carried out from the Aero Commander 680T, 6/n 0-2489 aircraft, specially converted for aerial photography and airborne laser scanning. The turboprop 680T Turbo Commander is equipped with two Garret AiResearch TREZZ1-43 turboprop engines with a capacity of 429 kW. The aircraft is equipped in accordance with the technical conditions for accommodation and operating rules on aircraft.

The flights over section 1 (figure 7) were performed at an altitude of 3200 m from the ground (according to Leica MissionPro calculations for the required density of laser reflection points of at least 4 per 1 m²).

The flights over section 2 (figure 7) were carried out at an altitude of 1500 m from the ground (according to Leica Mission Pro calculations for the required density of laser reflection points of at least 4 per 1 m²).
Figure 7. The flights over section 1 and section 2.

A permanent GLONASS / GPS / COMPASS / GALILEO station in Kotlas was used as a base station.

Flight survey work: aerial survey was carried out in accordance with the requirements of the Customer's Terms of Reference and the previously developed project. The flights were carried out in compliance with flight safety requirements. Meteorological conditions for aerial photography are favorable: slightly cloudy, visibility over 10 km. At the end of each flight day, the quality control of the received materials was carried out, the completeness of the coverage of the shooting area was made, a shooting plan for the next day was drawn up, considering the footage [7].

With the help of Leica CloudPro software, using the adjusted trajectory and the calculated misorientation angles of the scanner for each scanner channel, clouds of points of laser reflections in the .las format were formed (figure 8).

Figure 8. Clouds of points of laser reflections.

Initial inspection of airborne laser scanning materials was carried out in accordance with internal regulations in order to verify:
- compliance of survey parameters (height, speed, planned position) with design parameters;
- the quality of satellite data by the PDOP factor and the number of observed navigation satellites;
- availability of airborne laser scanning data and completeness of coverage of the object territory with laser reflection points.

The control was carried out directly at the facility for each flight day and included:
- unloading and transformation of onboard data;
- calculation of trajectories based on the results of GPS and IMU measurements;
- calculation and unloading of points of laser reflections;
- assessment of the density and uniformity of points of laser reflections;
- check of overlapping routes and completeness of coverage of the site.

Calculations were performed using software:
- "Inertial Explorer 8.70" - calculation of trajectories;
- "Leica CloudPro" - display of equalized points of laser reflections;
- "Leica HxMar" - display of photographs;
- "Leica IPASCO" - calculation of camera misorientation angles and display of exterior orientation elements;
- "MicroStation", "Terrasolid" - work with point clouds of laser reflections and digital elevation model.

The density of points of laser reflections was: 1 section - 2-3 points per 1 m², 2 section - 6-7 points per 1 m².

After the adjustment and classification of the point cloud, forest segmentation was carried out to obtain information about the characteristics of forest stands.

4. Summary

According to our estimates, no one has ever made such a recording in the world. The American company Zebra Imaging is conducting dual-purpose work in this direction, using other technologies. Currently, the company ceased operations. A multiplex hologram and a holographic plan of the area will add to the collection of the Optics Museum at ITMO University and took its rightful place at the last symposium. One of the holograms was donated to a gallery in New York. And further research and development will open a new direction in holography, which solves geoinformation problems. The developed methods will optimize the technology and provide a further cycle of research in this direction.

As a result of the assessment of the obtained materials quality, it was found that the area of the object was completely covered with airborne laser scanning materials, the position accuracy and density of laser reflection points corresponded to the planned one.

Analysis of aerial survey materials shows that they fully meet the requirements of regulatory documents.

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