Application of laser scanners and rangefinders technology in problem of industrial and natural objects control.

Vladimir Grigorievsky[1], Michael Prilepin[2], Vladimir Sadovnikov[1], Yuri Yakovlev[1]

[1] Kotelnikov Institute of Radio Engineering@Electronics RAS, Moscow region, Russia, Fryazino, Vvedensky place, 1

[2] Schmidt Institute of Earth Physics RAS, Moscow, st.Gruzinskaya 10

* E-mail of the corresponding author: vig248@rambler.ru;

Abstract

An overview of application of modern technology of laser scanners and range finders for measuring natural and industrial objects is done in this paper. The technique of phase measurements based on multi-frequency modulation of the laser radiation was proposed, which simplifies phase ambiguous resolution when measuring large distances to the object. A model of scanning allows effective spatial scanning of industrial and natural sites. On the basis of this model, scheme remote geophysical measurements was proposed, which encompasses corner reflectors , with the possibility of using active reflectors. Rangefinder with active reflector increases the range of the device several times. It can be effectively used in geophysical studies of Earth's surface and in control of shear deformations.

Keywords: laser, rangefinder, scanner, atmosphere, distance

1. Introduction

Over the past years a new trend of using laser ranging has been intensively developing in scientific-technological circles, laser scanning of natural surfaces and equipment followed by obtaining a three dimensional pictures in real -time has become a reality (Medvedev 2002).

The basis of measurement is the principle of combining two components, namely, optical rangefinder and navigation system GPS with inertial reference system (used for example in the case of air-based). The performance of a scanner is extremely high. The scanning speed may be 10^6 measurements or more per second.

A laser scanner allows creation of a 3D object's image – i.e. a cloud of laser points. This cloud allows to create a visual analysis of the natural object's shape and to perform necessary initial geometric measurements with accuracy at the level of about 1-10 mm.

The data obtained as a result of scanning have a natural three-dimensional format, which allows one to create high-speed data processing algorithm. This, in turn, leads to an efficient solution of task put by the customer. Aerial scanning is of practical value in the case of difficult access in remote areas, such as remote power lines, mines, dangerous mountain roads.

Ground-based and air-based laser scanning may be carried out without restriction, including objects and scenes with mild surface texture: surface water, tundra, sandy surface. However, it should be noted that better accuracy is achieved when ground-based imaging is performed (e.g. the accuracy 0.5 .... 5 mm) rather than air-based, due to the lack of vibration, as well as the possibility of a long accumulation of data on a scanned object.

The aim of this work is to develop methods of a laser scanner application with minor modifications to use in geophysical research in the measurement of large (~ 5 km) distances in the atmosphere, and the evaluation of the accuracy of these measurements. We will keep in mind the laser scanners that are based on a laser range finder, utilizing phase method of measuring the distance to an object and two angular displacement sensors.

2. Methodology

2.1 Overall block diagramm of the phase measurement technique and scanning by means of scanner.

Recently, several companies such as Leica, Basissoftware, Trimble and others has developed quite a few laser scanners models, allowing an accuracy of about ~ 0.5 - 1 mm up to 200 meters with the help of reflection from natural objects, such as building walls, constructions, woods, land, etc. The sensitivity to small changes in distances for periods of time on the order of a second can be much higher - tenths and hundredths of a millimeter. The energy potential of the Basissoftware scanner and its sensitivity were studied on the distances of 2.5 km when working with corner reflector. It was found out, that the sensitivity to small movements of the reflector is better ~ 0.1 mm, (0.01 mm for an averaging time of ~10 second) and the energy potential can be 30 km or more.

It should be noted that a recent series of compact frequency synthesizers provide an opportunity to develop a good method of phase measurement, because the transition from one frequency to another occurs in time ~ 1 ms; there is also an opportunity of multi-frequency modulation, which simplifies the phase ambiguity resolution when measuring at large distances. Here it is necessary to clarify that relationship between the phase of a signal and distance (D) from the object is described by formula (Asnis et. al.1995):

$$D = (2\pi N + \varphi)c / 2\omega \tag{1}$$

where φ - the measured phase of the signal frequency, and N - integer number of periods of the signal frequency that fits on a double distance (the so-called phase - ambiguity of measurements).
In the figure 1 a simplified diagram of the scanner is presented. Semiconductor laser is modulated by three frequencies: two low frequencies, for example, in the range of 10-13 MHz and a high frequency of ~ 700 MHz.

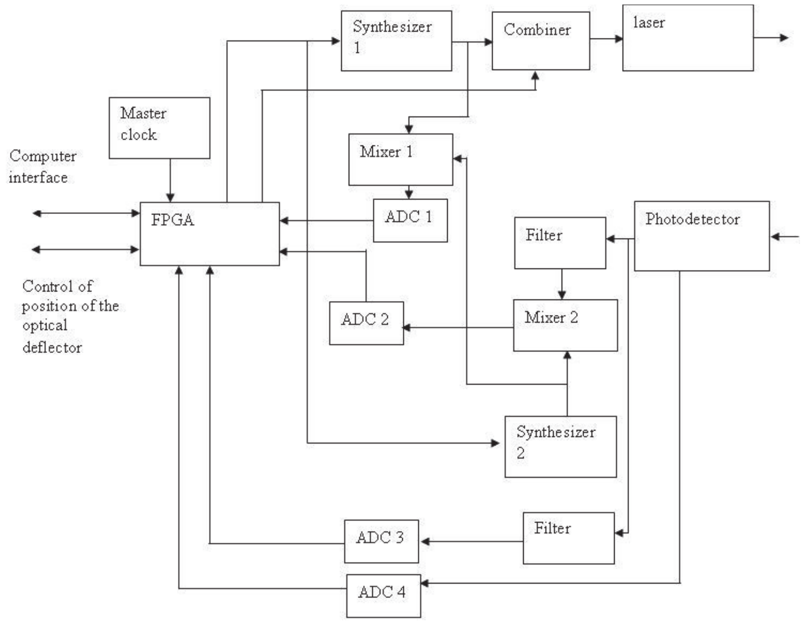

Figure 1. Block diagram of the scanning rangefinder.

This scanner was developed by Basissoftware and is described in patents (Yakovlev et al. 2002), (Petrov et al. 2011). The frequencies are combined in the adder and a modulated semiconductor laser, the light from which is directed to the object. All three frequencies are received by a photodetector, filtered by filters and directed to the appropriate analog-to- digital converters (ADCs): low frequencies directly , while high frequencies (the working and reference) - after conversion in the mixers 1 and 2. The digitized signals are sent to the programmable array (FPGA), which calculates the amplitudes and phases of signals by formulas:

$$S_x^p(t) = \int_{t-\tau}^{t} p(r)\sin(\omega \cdot r)dr \tag{2}$$

$$S_y^p(t) = \int_{t-\tau}^{t} p(r)\cos(\omega \cdot r)dr \tag{3}$$

where $\omega = 2 \cdot \pi \cdot Fd$ - intermediate frequency after the mixers, τ - the time of one measurement (integration time), p (t) -signal after the first mixer (reference signal), $S_x^p(t)$, $S_y^p(t)$ - the convolutions of the reference signal. Using (2) and (3) the phase $\varphi^p(t)$ and amplitude $A^p(t)$ of the reference signal are according to the formulas will be:

$$\varphi^p(t) = arctg(S_x^p(t) / S_y^p(t)) \tag{4}$$

$$A^{p}(t)=\sqrt{(S_{x}^{p}(t))^{2}+(S_{y}^{p}(t))}^{2} \quad (5)$$

Similarly, for a received signal q (t), we have:

$$S_{x}^{q}(t)=\int_{t-\tau}^{t} q(r)\sin(\omega\cdot r)dr \quad (6)$$

$$S_{y}^{q}(t)=\int_{t-\tau}^{t} q(r)\cos(\omega\cdot r)dr \quad (7)$$

$$\varphi^{q}(t)=arctg(S_{x}^{q}(t)/S_{y}^{q}(t)) \quad (8)$$

$$A^{q}(t)=\sqrt{(S_{x}^{q}(t))^{2}+(S_{y}^{q}(t))}^{2} \quad (9)$$

After calculating the convolutions in the FPGA, the data is sent to the PC via USB, where we calculate distances and angles of scanning. Amplitude data is used in the computation process to refine the measured distances. The averaging time can vary from 1 to 10 microseconds, the corresponding band of the digital filter is 106 - 105 Hz. Low frequencies are selected for reasons of phase ambiguity resolution: for maximum distance ~ 100 meters difference between the low frequencies should be less than $F\sim c/2D=3\cdot10^{8}/2\cdot100=1500$ kHz, since the phase difference ψ of modulation frequencies should not exceed the limit of resolution of ambiguity phase 2π:

$$\psi=2\cdot\pi=4\cdot\pi FD/c \quad (10)$$

where c - speed of light, F - the difference frequency, D – distance.

2.2 Experimental results

Main characteristics of the created devices are specified on the site (www.basissotware.com) and are presented in table 1 below:

Table 1.Characteristics of the group scanners firm Basissoftware.

Configuration	Short range	Mid range	Far range	Extra far range
Range ambiguity resolution, m	180	180	180	180
Recommended operating range, m	1-35	1-50	1-75	1-120
Rms error range, mm	0.07 on 10 m	0.16 on 10m	0.16 on 10m	0.3 on 10m 3 on 100 m
Scan speed, points/ sec	to 1200000	to 1200000	to 1200000	to 1200000

Figures 2,3 show data for three-dimensional scanning and modeling of tidal power turbines and aircraft fuselage "Boing747."

Figure 2. Scanning and modeling of tidal power turbines

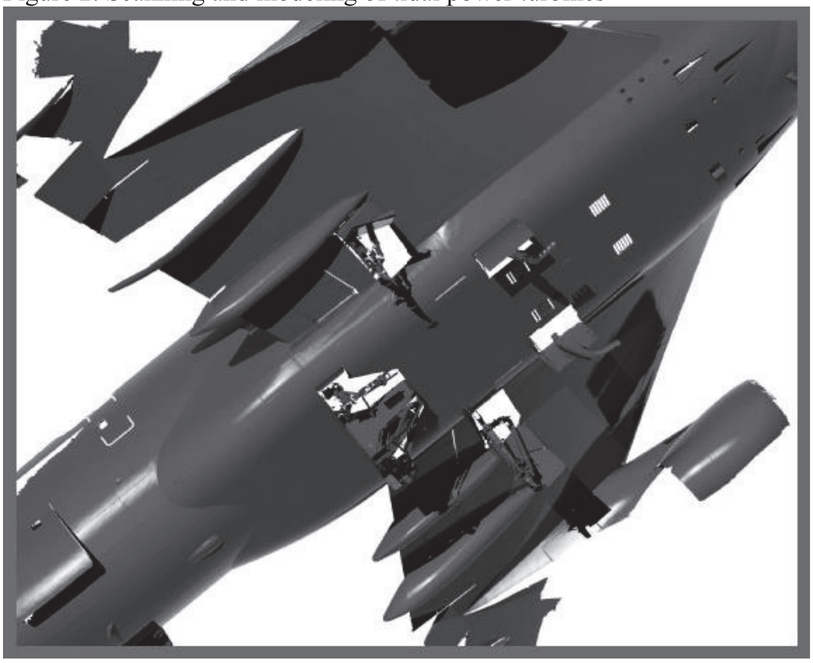

Figure 3. Scanning and modeling of aircraft fuselage of "Boing747".

Three-dimensional model data means that the array of points with coordinates of the object (scan) can be analyzed in any three-dimensional graphics program, such as Acad, and the distance between any two points can be displayed on the screen with an error ~ 0.5 mm.

3. Prospects for application scanners in geophysical investigations.

3.1 Study area

Studies show that the accuracy of the phase scanner at a distance of up to 100m can be better than 1 mm, and sensitivity can be times better. With such accuracy and sensitivity this scanner can be used to measure long distances in atmosphere. However, to compensate for atmospheric instability, it is necessary to introduce laser emitting in the blue region of the spectrum. That is, starting with the distance of ~ 1 km one should use two-wavelength method (dispersive method) to measure distances (Grigorievsky et al. 2011).

The basic formula to determine the distance D by means of dispersive rangefinder is written as follows (Asnis1995 et al., Grigorievsky et al. 2009):

$$D = L_1 - f(\lambda_1)\cdot(L_1 - L_2)/\left[f(\lambda_1) - f(\lambda_2)\right] \quad (11)$$

where L1 and L2 - optical lengths that are measured by means of device, f(λ) -- a function that depends only on the wavelength of light. In the case of lasers with a wavelength spacing from λ_1 to λ_2 the value A=f(λ_1) / $\left[f(\lambda_1) - f(\lambda_2)\right]$ (the so-called dispersion coefficient defined at the edges of the spectral range $\lambda_1.....\lambda_2$)) is from ~ 10 to 150. It is determined by the following formula linking the refractive power of air N and function $f(\lambda)$:

$$\frac{f(\lambda_1)}{\left[f(\lambda_1) - f(\lambda_2)\right]} \cong \frac{N(\lambda_1)}{\left[N(\lambda_1) - N(\lambda_2)\right]} \quad (12)$$

Given this, an equation (11) can be rewritten as:

$$D=L_1- A\cdot(L_1 - L_2), \quad (13)$$

And distance measurement error will be:

$$\delta D \approx \delta L_1 + A\cdot\delta(L_1 - L_2) \quad (14)$$

However, it is worth pointing out that the main drawback of this type of devices is the limit set by the strong absorption of radiation in the Earth's atmosphere in the blue-green region of the spectrum as it propagates from the transmitting point to the reflector and back. In (Grigorivsky et al. 2011) on the basis of the Bouguer law there were made numerical calculations of maximum range of rangefinders, which depend on the range of meteorological conditions and radiated power. For pure atmosphere, when the meteorological visibility is S_{mv} ~ 10 km, we can write for the absorption coefficient $\alpha(\lambda)$ of light in the atmosphere (Bayborodin et al. 1978) the following:

$$\alpha(\lambda) = \left(3.91/S_{mv}\right)\cdot\left(\lambda/0.55\right)^{-n} \quad (15)$$

where n = 0.585, λ - the wavelength.

The formula for distance range D has the following form:

$$D = \ln\left(I_2/I_1\right)\cdot\left[\left(-3.91/S_{mv}\right)\cdot\left(\lambda/0.55\right)^{-n}\right] \quad (16)$$

where I_1- the radiated power and I_2 - the received power of laser.

3.2 Results and Discussion

Analysis of the calculations shows that the maximum range of two-wavelength rangefinder, which uses a corner reflectors, does not exceed ~ 30 km at an average meteorological visibility ~ 10 km in the atmosphere and for laser power levels of ~ 40 milliwatt. Nevertheless, it follows from (14), when A ~ 20 (for the laser wavelengths ~ 0.44 and 0.65 micron) the measurement error of greater distances will be 20 * 0.1 mm = 2 mm when the measurement error (L1-L2) is 0.1 mm. The necessary block in the scanner is a blue laser, (figure 4) and proper choice of low frequencies which helps increase the range of measured distances.

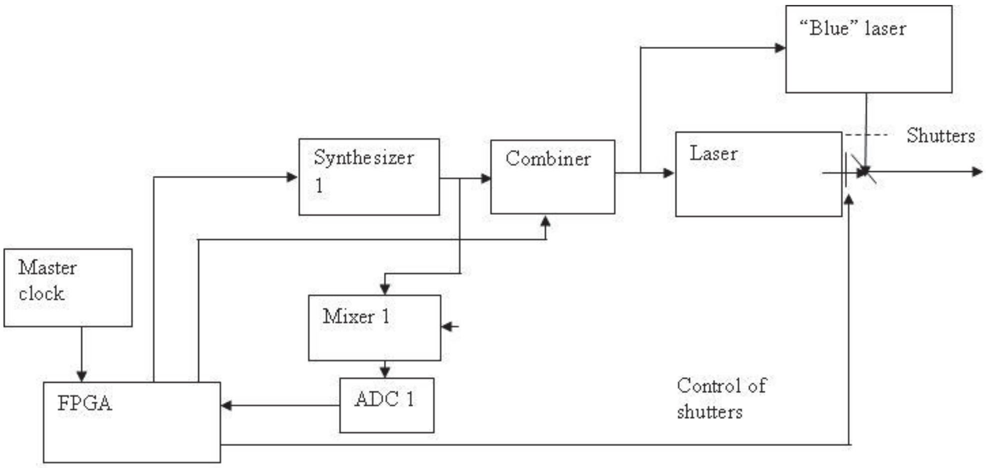

Figure 4. Changes in the modulation block of the scanner for measuring a large distances in the atmosphere.

The channels with red and blue lasers and interference filters in front of the photodetector are switched synchronously. Also, since laser power should be no more than ~ 40 mW (for medical safety standards of view), it is necessary to work, as mentioned above, with the corner reflectors that increase the range of the instrument. To increase the energy potential of the instrument is possible to use the optical beam expander. That is, if one uses additional output lens of diameter 200 mm (the diameter of the front lens of scanner is 60 mm), the divergence of the radiation can be reduced more than 3 times. Besides, the output power density of the laser radiation is reduced in ~ 10 times; that is why one can use more powerful lasers: in this case about 200 mW does not exceed medical norms. Let us consider the possibility to use the scanner to study the Earth's crust displacement and to predict abnormal natural phenomena such as an earthquake or tsunami. As long-term researches of seismic events in the field and laboratory conditions show, primary characteristics of earthquake preparation in a seismically active region of deformation processes are caused by the accumulation of stress. Therefore, among the major precursors of earthquakes (their order of 200) there are displacements of terrestrial rocks and slopes of the Earth's surface. The polygons for earthquake prediction have been described in scientific literature; there the GPS system with tens and hundreds of receivers on the seismically active zones was chosen as a main tool for strain monitoring (Prilepin 1994). In our opinion, a worthy addition to this kind of polygon measurements will be the measurements done on land surveys scanners, and such devices should measure an area of ~ 50 * 50 km. The scanner should have a few (20 .... 40) characteristic points, which coordinates are to be determined. One must install the mirror- corner reflectors – at these points and periodically scan them several times a day with the operational information processing and delivery of data in Analytical Service Forecast for Seismic Situation.

It must be emphasized that for successful forecasting activities one must have a reliable devices with advanced telemetry and computer software, that provide a real picture of deformations at least 3-4 times a day. At the initial stage it is possible to have a variant of the parallel activity in a seismically active and quiet zones. In this case, the accuracy of the measurements 10^{-7} ... $5 * 10^{-8}$ can be accepted as the stability of the spatial coordinates of the measured points. Developments, obtained on stable zone can be transferred to seismically active zone, operating in a continuous observation. For ultimate precision coordinate measuring ~ 5.10^{-8} on multiple distances the temperature and barometric measurements must be done with sensors or remote sensors to monitor the meteorological parameters.

To increase the range of scanners and a correspondingly larger area coverage, one may increase an average power of laser sources, diverse it into pulse mode or use so-called active reflectors (Grigorievsky et al. 2011, Prilepin et al. 2012), when the blue part of the spectrum goes only to the reflector, but the red part passes to the reflector and back. As shown in (Grigorievsky V.I.at al.2012), the use of such active reflectors increases the distances range several times. Numerical results of the calculation range of the scanner according to the range of meteorological visibility Smv of atmosphere for two cases of the spectrum is shown in figure 5.

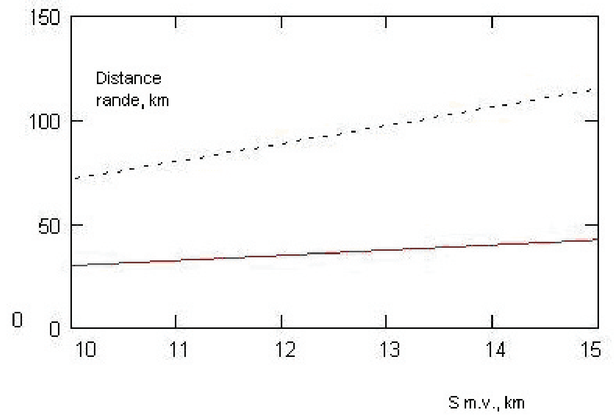

Figure 5. Distances range D of the scanner according to the range of meteorological visibility Sm.v. of atmosphere for two cases of the spectrum

The dotted curve corresponds to rangefinder with "active reflector" when the blue spectrum of laser light goes the distance only to the reflector but infrared region of the spectrum - to the reflector and back. Pointing accuracy on corner reflectors constituting geodesic grid, (when a width of the radiation pattern 10^{-4} rad. and corner reflectors diameter ~ 30 cm) is ~10-20 seconds of arc; this is really achievable in scanner technology, because the accuracy of the reference angle is better than 15 arcs (www.basissotware.com). Possible modification of the guidance system is the use of a suitable guidance system, which is used for astronomical telescopes (www.celestron.com). Time of single measurement may be more than 1 sec. In this case, components of high-frequency noise are significantly weakened, including atmospheric turbulence turbulence (GrigorievskyV.I at al 2009), which also increases the sensitivity of the apparatus . For long-term monitoring it is necessary to periodically compare the frequency of the internal crystal oscillator with a highly stable frequency standard with relative frequency instability better than 10^{-10} - 10^{-11}, since the internal crystal oscillator device does not have these characteristics.

4. Conclusions

In the paper one of the working models of scanner and the results of 3D scanning of some industrial and commercial facilities are considered. Also a technique and technology of specific laser scanner application (with minor modifications) to use in geophysical investigations for measuring long (~ 5 km) distances in the atmosphere is proposed; and the accuracy of these measurements is evaluated.

Application and development of this technology, in our opinion, is a promising direction in laser ranging in geophysical measurements, in terms of accuracy and efficiency of data acquisition at ranges of over 30 km when using corner reflectors and active reflectors. This laser scanner complex may be one of the elements in the system of operational prevention of emergencies and natural disasters.

References

Medvedev E.M. (2002), Simultaneous Recording of LIDAR and Aerial Imagery//GIM International, №1, p.10.

Yu. O. Yakovlev, V.I. Grigorievsky, A.V. Asrelin, A.V. Sherstuk, P.M. Petrov (2002), “Three dimensional optical scanner”, US Patent 6,483,595 B1.

Petrov P, YakovlevY, GrigorievskyV, .Astrelin A,Sherstuk (2011) A Binary modulation rangefinder, US Patent № 7 973 912 B2, Jul.5.

Asnis L.A., Volkonsky V.B., Yakovlev V.V. (1995), Laser ranging, Radio and communication, Moscow , pp.80.

Grigorievsky V.I., Grigorievskay M.V., Sadovnikov V.P, Prilepin M.T. (2011), Application of laser scanners technology and range finders in hydrodynamics and seismicity environment problems. J. Ecological systems and devices, RF, v.11, pp.9-14.

Prilepin M.T. (1994) Using global satellite systems for the study of crustal deformation.Dynamics of a continental lithosphere. Mobile belts, under the editorship of A. Logacheva, V.Hromovskih. Moscow. Nedra.

Prilepin M.T., Grigorievsky V.I., Egorov F.A., Sadovnikov V.P. (2012). Dispersive laser rangefinder with an enhanced range, Patent RF, №112399.

GrigorievskyV.I., Grigorievskay M.V., Sadovnikov V.P., Prilepin M.T. (2009), Effects of the refraction of atmosphere on the accuracy characteristics of the subpicosecond dispersive range finder in the conditions of strong turbulence on extended distances, J. Electromagnetic waves and electronic systems, RF, v.14, №6, pp.49-55.

http://www.celestron.com/astronomy/celestron-cpc-1100-gps-xlt.html

Handbook of laser technology. Edited by Bayborodin Y.V. (1978), Kriksunov L.Z., Litvinenko O.N., Kiev., Technics.

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