The measuring accuracy study of the light mark coordinates of laser modules

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Abstract. Measuring systems using the design of laser module beams on the surface of the object under study are considered. A technique is proposed for experimental researches of the brightness structure of the study of laser modules. Adaptive algorithms on the type of module and distance have been developed for determining the coordinates of light marks on the surface of controlled products. The need for high-precision measuring systems to carry out their pre-liminary selection and calibration of laser modules according to the proposed method, taking into account the range of design of light marks, is shown. It is shown in the work that the accu-racy of determining the relative coordinates in the trajectory of the light marks of laser mod-ules for monochromatic targets can be several times higher (0.2 - 0.3 mm) than the accuracy of determining their absolute coordinates (≈ 1 mm).

1 Introduction

Laser modules are widely used in instrumentation systems of various branches of technology, where it is necessary to accurately determine the coordinates of the light mark on the projected surface. Such applications include photogrammetry [1], control of crystal cutting [2], systems of target designation, navigation, etc. Currently, inexpensive semiconductor laser modules with low divergence are widely used. The radiations of such modules have a large scatter of parameters and significant variations in the brightness structure at different radiation design distances.

The measurement of the true size and other characteristics of the cross section of the laser beam during its propagation and the formation of the light mark on some surface is associated with certain difficulties, which are determined by the optical properties of the surface and the properties of the optical design system of the light mark on the recorder of photodetector. This primarily affects the accuracy of determining the coordinates of light marks. Important issues are the choice of an optoelectronic system, an algorithm for processing images of light marks and an algorithm for measuring their parameters. Currently, these issues are being successfully solved in particular problems, under given fixed conditions. The main difficulties are the brightness structure of laser emitters that is unstable from a distance and the lack of a calibration method for a measuring system in a

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wide range of uncontrolled conditions.

Studies of the brightness structures obtained on the surface by laser modules have not been previously conducted. The solution to the problem of determining the coordinates of light marks in a wide range of distances of their design and of various types and instances of laser modules is very relevant, as it will improve the accuracy of devices based on them and expand the scope of their application.

2 Method overview

The radiation parameters of the laser modules are determined by the characteristics of the used laser LED, as well as their integrated optical system for the formation of radiation. The radiation structure of the laser module (mode composition) is determined by the design of the laser resonator [3]. The active element of the laser and the resonator form the spectral and mode composition of the radiation, which determines the spatial structure of the beam and the angular divergence of the radiation. At the same time, the accuracy of sighting of the optoelectronic system (OES) by the laser emitter marks is determined by the ability to determine the coordinates of the light spot on the surface of the object by means of some additional optical system, which is determined by the type and resolution of the recording sensor. In the selection and subsequent use of laser modules, it is necessary to control and take into account not only static, but also dynamic characteristics of determining the coordinates of light marks [4].

For registration of the distribution of the brightness structure is currently using matrix photodetectors based on matrices of photodiodes of the CCD and CMOS type [5], which makes it possible to automate the input of the image of the studied brightness structure into a computer system and its subsequent processing. In this case, there are single registration schemes (single-point) and multi-position. Hybrid OESs are being developed at present, which make it possible to record the coordinates and directions of the rays OES [6], which are an array of digital cameras of low resolution. The specified solution allows expanding the dynamic brightness range, excluding the mutual influence of photodiodes.

National Instruments (NI) technologies are widely used to input brightness fields from the OES registrar, which include the LabVIEW graphical programming environment [7], algorithm development tools (NI Vision Assistant), and construction of industrial automated control tools (NI Vision Builder for Automated Inspection) [8, 12].

Currently, mathematical methods of signal processing based on the joint time-frequency (JTFA) and wavelet analysis (WA) [9], which are implemented by the NI Advanced Signal Proceedings Toolset additional module, are widely used. These methods make it possible to increase the accuracy of measuring weakly localized brightness structures under noise and mechanical instability of the control system.

Thus, to conduct research on the accuracy of determining the parameters of laser modules, it is advisable to use technologies and solutions of National Instruments, which allow you to create and test prototypes of industrial and embedded systems, to carry out their modernization and scaling.

3 Research facilities

As an OES, we used a smart camera from National Instruments (NI) – NI 1742 [10] equipped with a 533 MHz PowerPC processor. Smart camera sensor is monochrome CCD with a resolution of 640×480 *Pixels* (VGA) (Sony ICX424AL) 1/3 inch in size (effective image area 5.8×4.9 *mm*, pixel size 7.4 *microns*).

Alternatively, a light field recorder (LF) based on a digital camera (DC) Lytro ILLUM

(version B5-0036 ILLUM) [11] with a CMOS sensor (Aptina MT9F002 14.4 *Mpix*, 1/2.3″, effective image area: 6.14×4.6 *mm*, pixel size 1.4 *μm*) was used. The number of microlenses in the array is 130,000 (focal length 25 *microns*, pitch 13.89 *microns*). The resistor had an integrated lens of 9.5-77.8 *mm* with a relative aperture of *f*/*D*=1:2. For processing LF files, the original Lytro Desktop application was used. Maximum resolution of the DC: 2450x1634 *Pixels*.

A high-resolution digital camera EOS 6D, a Celestron NexStar 4 SE telescope (*D*=102 *mm*, *f'*=1325 mm), Sky-Watcher BK MAK90SP (*D*=90 *mm*, *f'*=1250 *mm*), Celestron C70 Mini Mak (*D*=70 *mm*, *f'*=750 *mm*) were used in the studies.

The following laser modules were used in the work: No. 1 - LXGD LG-4C (□=630–680 *nm*, P *P*=< 5 *mW*), No. 2 - LTSU-OM (□=630–650 *nm*, *P*=< 3 *mW*).

4 Research

For a direct study of the structure of the radiation profile of the propagating laser module ($I(x,y)$) at a given distance S, a scheme of the experimental setup is presented, shown in Fig. 1. The goal is to determine the geometric parameters of the brightness structure of the beam of laser modules depending on the distance S:

$$\{D, d_1, d_2, \theta, l, S, ...\} = F_p(s), \quad (1)$$

where $F_p(s)$ is the functional dependence of each geometric parameter of the light spot on the distance.

Fig. 1. The scheme of the experimental setup for measuring the parameters of laser modules: 1 – laser module; 2 – light filter; 3 – digital camera; 4 – software

An image of the brightness structure of the beam in the plane of the sensor of laser module No. 1 at a distance of 350 *mm* is shown in Fig. 2.

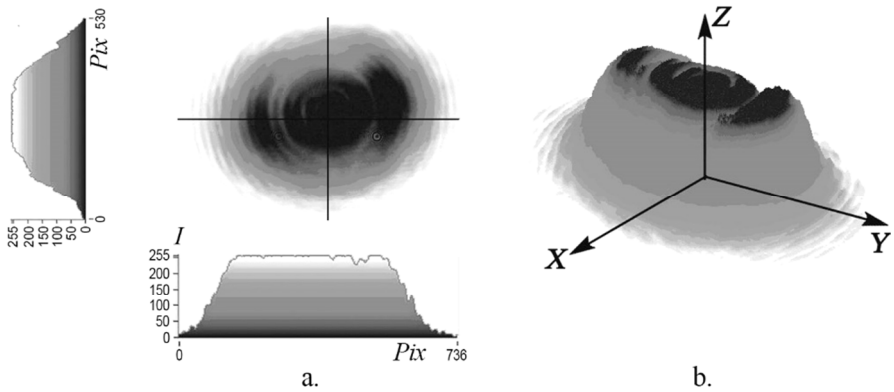

Fig. 2. The brightness structure of the laser radiation of the laser module No. 1: a. Flat model; b. Three-dimensional model

It can be seen from the obtained three-dimensional model that the light spot has a certain shape close to an ellipse, as well as a finer construction structure, including interference rings associated with defects in the optical system.

For a more detailed measurement of the main geometric parameters of the beam spot of the laser module, the technology of virtual instruments (VI) by National Instruments (NI) was used [7]. An algorithm (script) for image processing and measuring its parameters is created in the NI Vision Assistant application (Fig. 3). The image processing and measurement functions used are described in detail in [8].

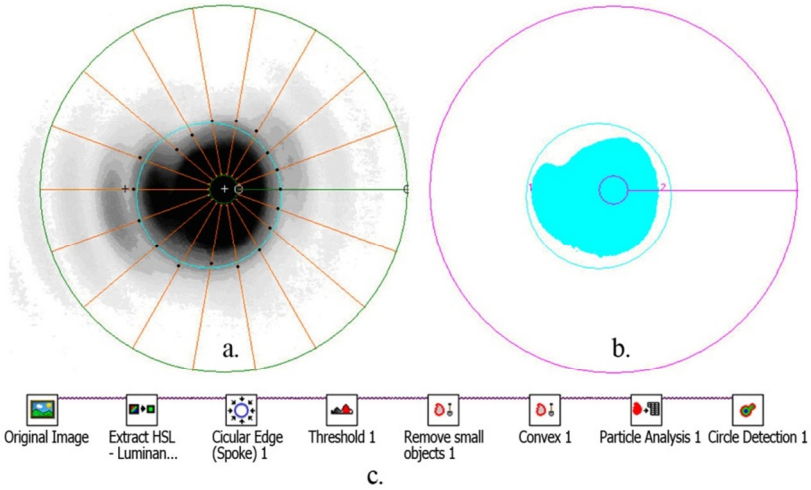

Fig. 3. The script of processing and measuring the image light mark: a. Illumination distribution in the light mark of the laser module; b. Binary form of a light mark; c. Image processing script

Of practical interest is the registration of images of light marks from small and large distances. Therefore, various optical systems (lenses) were used to efficiently register light marks from various distances: Canon EF-S 18-200mm *f*/3.5-5.6 IS (74°20'- 7°50'); Canon EF 70-300 mm *f*4-5.6 IS USM (29° - 6°50', 19 ° - 4°35', 34° - 8°15'); Canon EF 100-400mm *f*/4.5-5.6L IS USM (20° - 5°10', 14° - 3°30', 24° - 6°10'); SKY-WATCHER MAK90EQ/TA, (*f'*=1250 mm, *D/f'*=1:13.5).

The use of telephoto optics increases the requirements for the mechanical stability of the recording system, complicates the measuring system in real conditions.

An important application is the task of controlling the movement of the rifle barrel during the aiming process. Therefore, the measurement of the parameters of the trajectory of motion is proposed in the optical scheme shown in Fig. 4.

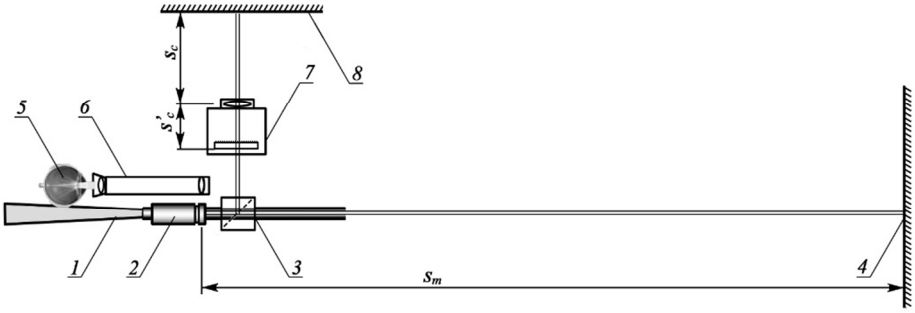

Fig. 4. Measurement of coordinates and trajectories of the laser module marks: *1* – rifle barrel; *2* – laser module; *3* – beam splitter; *4* – screen - target; *5* – human eye; *6* – telescopic tube; *7* – digital camera; *8* – additional screen

The parameters of light marks of laser modules for various types of targets were studied by registering with a digital camera from various distances. Using the image processing algorithm, the geometric characteristics of the shape of the light mark and its coordinates were determined (Table 2). The functions Circular Edge (Spoke), Particle Analysis and Circle Detection gave different coordinate values - (X_b, Y_b), (X_m, Y_m), (X_c, Y_c), respectively. The deviation of the results obtained using various functions reflects the accuracy of the measurement of coordinates:

$$\Delta X_{mb} = X_m - X_b, \quad \Delta Y_{mb} = Y_m - Y_b, \quad \Delta r_{mb} = \sqrt{\Delta X_{mb}^2 + \Delta Y_{mb}^2},$$

$$\Delta X_{cb} = X_c - X_b, \quad \Delta Y_{cb} = Y_c - Y_b, \quad \Delta r_{cb} = \sqrt{\Delta X_{cb}^2 + \Delta Y_{cb}^2}.$$

The measurement result was influenced by the parameters of the shooting parameters and image processing settings. The measurements are determined by the choice of parameters by the built-in measurement function Particle Analysis 1. Table 1 presents the results for the following parameters: best radius (R_b); maximum diameter (D_{max}); radius of the inscribed circle (R_c).

Table 1. The results of determining the parameters of the laser module marks

Parameter	Distance S, m							
S, m	3.0	4.0	5.0	6.0	7.0	8.0	10.0	14.0
β_0	0.11	0.081	0.064	0.053	0.045	0.040	0.031	0.022
$2 \cdot R_b$	67.9	52.3	43.84	36.92	36.35	30.84	33.35	28.82
D_{max}	154.5	118.3	98.98	88.6	82.56	68.71	70.11	63.32
$2 \cdot R_c$	52.0	41.0	35.0	29.0	26.0	24.0	26.0	24.0

Measurement deviation of light mark coordinates made by different methods is presented in Fig. 5. It is seen that the dependences □$r(s)$ are of a general nature, which indicates the characteristic features of the laser module.

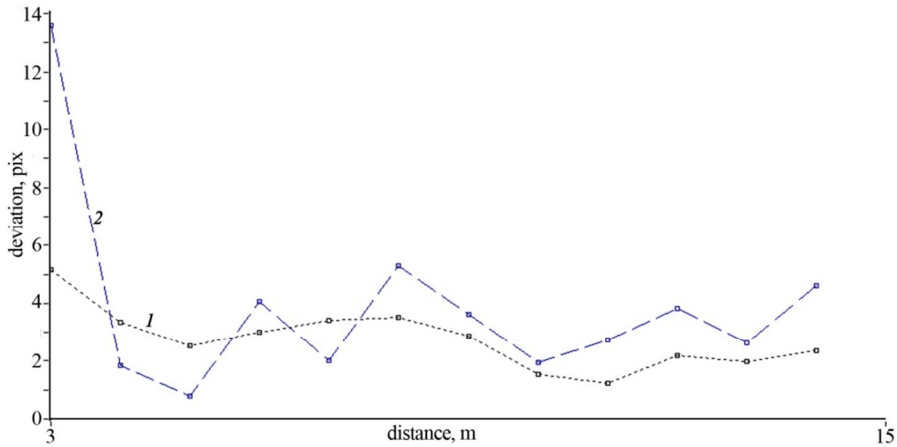

Fig. 5. The dependence of the measurement deviation of the mark coordinates of the laser module on the design distance: *1* – □r_{mb}; *2* – □r_{cb}

5 Conclusions

Studies have shown that the accuracy of determining the relative coordinates in the trajectory of the light labels of laser modules for monochromatic targets is several times higher (0.2 – 0.3 *mm*) than the accuracy of determining the absolute coordinates of the light marks of the laser module (≈ 1 *mm*). It can be concluded that in order to increase the accuracy of measuring the coordinates of the light marks of the laser module by means of technical vision, it is advisable to preselect them according to the presented methodology, taking into account their range. To work in a wide range (especially for semiconductor lasers), it is advisable to use customizable graduated optics of the laser module. The accuracy of determining the coordinates and the shape of the light marks of the DC LF is 1.5 higher, however, they require considerable time for processing the LF file. Using a smart camera allows creating ready solutions with high speed.

To register the light marks of the laser module, it is advisable to use a telescopic system that allows getting the minimum field of view of the optical system, i.e. the maximum size of the light reference marks on the surface of the sensor. However, the use of a telescopic system for recording from short distances is impractical due to the low aperture ratio and distortions of the optical system.

References

1. T. Luhmann, S. Robson, S. Kyle, J. Boehm *Close-Range Photogrammetry and 3D Imaging* (de Gruyter, Berlin, 2014)
2. V. E. Makhov Journal of mining institute, **209,** 119-123 (2014).
3. A.A. Popov, V.V. Sherstnev, Yu.P. Yakovlev, Physics and Technology of Semiconductors, **32(9).** 1139-1144 (1998).
4. I.I. Sytko, E.A. Kremcheev, V.E. Makhov *Device for measuring relative amplitude-frequency characteristics*. Patent No. 2668951 of the Russian Federation (2017)
5. G. C. Holst, T. S. Lomheim *CMOS/CCD Sensors and Camera Systems*6(SPIE PRESS BOOK, Second Edition, 2011)

6. J. Kučera, *Computational photography of light-field camera and application to panoramic photography*. Master thesis: (Prague, 2014)
7. J. Travis, J. Kring *LabVIEW for Everyone: Graphical Programming Made Easy and Fun*, Third Edition: (Prentice Hall, 2006)
8. T. Klinger *Image processing with Labview and Imaq Vision (National Instruments Virtual Instrumentation Series)* (Prentice Hall Professional, 2003)
9. C.K. Chue *An Introduction to wavelets*. (Academic Press, 2001)
10. A.I. Potapov, V.E. Makhov, Y.G. Smorodinskii, E.Y. Manevich, Russian Journal of Nondestructive Testing. **55(7)**, 524-532 (2019)
11. R. Ng *Digital light field photography*. PhD dissertation (Stanford university, 2006)
12. N.V. Maksarov, J. Olt. Journal of mining institute **226**. 446-451 (2017).