ENGINEER

international scientific journal

ISSUE 2, 2026 Vol. 4
E-ISSN
3030-3893
ISSN
3060-5172

A bridge between science and innovation

TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
Tashkent state transport university

ENGINEER

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E-ISSN: 3030-3893

ISSN: 3060-5172

VOLUME 4, ISSUE 2

JUNE, 2026

engineer.tstu.uz

TASHKENT STATE TRANSPORT UNIVERSITY

ENGINEER

INTERNATIONAL SCIENTIFIC JOURNAL
VOLUME 4, ISSUE 2 JUNE, 2026

Founder of the international scientific journal “Engineer” – Tashkent State Transport University, 100167, Republic of Uzbekistan, Tashkent, Temiryo‘lchilar str., 1, office: 465, e-mail: publication@tstu.uz.

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Tashkent State Transport University had the opportunity to publish the international scientific journal “Engineer” based on the **Certificate No. 1183** of the Information and Mass Communications Agency under the Administration of the President of the Republic of Uzbekistan. **E-ISSN: 3030-3893, ISSN: 3060-5172.** Articles in the journal are published in English language.

Issues of using fiber-optic elements for constructing a ground-based distributed system for measuring solar optical radiation

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Abstract: This article is devoted to the development and optimization of star-shaped structures for measuring solar optical radiation using fiber optic cables. The feasibility of optimizing the star-shaped structure of a measuring system for estimating solar radiation in radial directions from the center of the study area is examined. It is shown that using a star-shaped structure to measure temperature in radial sectors of a circular zone can achieve a twofold improvement in signal-to-noise ratio compared to measurements using diametrically positioned fiber optic cables.

Keywords: solar radiation, measuring system, star structure, optimization, fiber optic cable

1. Introduction

As noted in [1], the method of distributed measurement of solar radiation using fiber optic elements allows for long-term measurements with high spatial resolution. According to [2,3], distributed fiber optic sensors/hereinafter DFOS (Distributed Fiber Optic DFOS sensors enable distributed positional measurements of physical quantities such as temperature, pressure, and mechanical stress along a fiber optic cable laid in a specific direction. These sensors can replace a large number of independent discrete elements, which are typically installed at intervals along the objects being monitored. This makes it possible to monitor over fairly long distances, up to tens of kilometers. The use of DFOS reduces power consumption and system cost. According to [1], DFOS are not subject to aging and allow multiplexing while simultaneously performing quasi-static measurements.

One of the promising areas of application of DFOS is undoubtedly the measurement of solar optical radiation on the Earth's surface. As noted in [4], the relevance of such measurements lies in the fact that the Sun is an important source of energy for our planet, and any small change in this energy can affect such crucial areas as agriculture, climatology, and energy. As noted in [5], ground-based solar radiation measurements are still the most accurate compared to remote measurements from onboard various aircraft. At the same time, distributed measurements of solar radiation using DFOS , have a disadvantage, which is that the physical processes used in them (Rayleigh, Brillouin , Raman scattering) are subject to the influence of temperature [6,7], pressure, mechanical stress [8,9].

According to [4], the technology of distributed solar optical radiation measurements is based on the principle of bolometers , which consists in the fact that the power of the acting electromagnetic radiation can be established by determining the temperature of a material whose absorption coefficient is known.

Moreover, if the temperature of such a material in the absence of solar radiation is known, then the temperature of the said material can be determined by the formula

$$T(t) = T_0 + \left(\frac{E_{inc} \cdot A_{inc} \cdot \alpha}{hA}\right) \cdot \left(1 - \exp\left(-\frac{hA}{cm}t\right)\right) \qquad (1)$$

where is $t$the time of exposure of the material to solar radiation; $E_{inc}$is the density of solar radiation; $A_{inc}$is the area of the solar radiation absorber; $\alpha$is the absorption coefficient, $h$is the coefficient of heat transfer to the associated element with temperature T_0; $A$is the area of heat transfer to the element with temperature T_0; $c$is the specific heat of the absorber; $m$is the mass of the absorber.

It should be noted that direct application of the bolometric principle in distributed fiber-optic solar radiation measurement is complicated by the fact that the ambient temperature along the fiber-optic cable's path is initially unknown. To address this issue, two fiber-optic cables containing surface layers with different absorption coefficients are used in the selected monitoring direction.

As shown in [4], in this case the solar radiation flux density can be determined by the formula

$$E_{inc} = \frac{T_2 - T_1}{c_2 - c_1} \qquad (2)$$

where is $T_1$the temperature of the first cable; $T_2$is the temperature of the second cable; $c_1, c_2$are constants defined as

$$c_1 = \frac{A_{inc}\alpha_1}{h_1 A} \qquad (3)$$

$$c_2 = \frac{A_{inc}\alpha_2}{h_2 A} \qquad (4)$$

The principle of two cable measurements $E_{inc}$is illustrated in Fig. 1.

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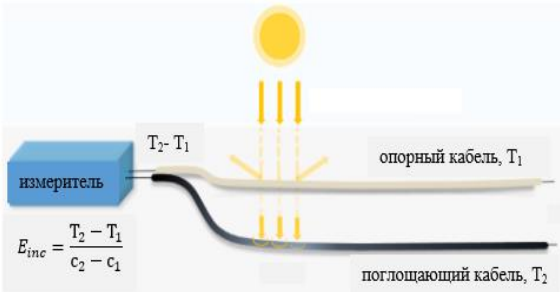

Fig. 1. Illustration of two cable measurements of solar optical radiation density

The signal-to-noise ratio can be estimated using the formula

$$S_{1inc} = \frac{T_2 - T_1}{(c_2 - c_1)\Delta T_{ш}} \quad (5)$$

where are $T_{ш}$the noises in temperature determination due to the influence of the external factors mentioned above. We formulate the research problem as follows:

It is necessary to carry out measurements E_{inc}on a circular area by constructing a star-shaped DFOS structure , an illustration of which is shown in Fig. 2. In this case, it is permissible to use radially directed DFOS , shown in Fig. 1, in which the absorption coefficientsα_i c leave an ordered set

$$A = \{\alpha_i\}; i = \overline{1,n} \quad (6)$$

$n$radially installed gauges by sector .

The times (durations) of temperature measurements in such meters installed along a sector of a circular area (Fig. 2) denoted as $t_j$also constitute an ordered set T, where

$$T = \{t_j\}; j = \overline{1,n} \quad (7)$$

It is also necessary to estimate the gain in the signal-to-noise ratio when carrying out measurements on a star-shaped structure of sensors compared to the result of measurements along a diametrical path along a circular area using one extended section of an absorption meter, the signal-to-noise ratio of which can be estimated using formula (5).

2. Research methodology

Let us consider a distributed star-shaped structure of a solar optical radiation density meter (Fig. 2).

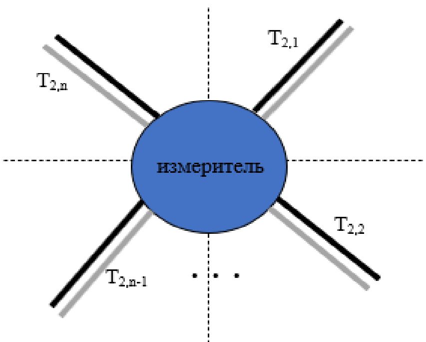

Fig. 2. Illustration of a star-shaped structure for the implementation of distributed measurements of solar radiation density with n number of sections in the study area

For a star-shaped distributed system, one may require the signal-to-noise ratio to increase to an extreme value. In the discrete case discussed above, the optimal relationship should be determined.

$$t_j = f(\alpha_i) \quad (8)$$

at which the average value of the signal-to-noise ratio across sectors, defined as

$$S_{cp} = \frac{1}{(c_2 - c_1)\Delta T_{ш}}\left[\frac{1}{\pi}\sum_{i=1}^{n}(T_{2i} - T_1)\right] \quad (9)$$

would reach extreme values.

If we accept constancy T_1across all sectors and $T_1 = 0$then the research problem is reduced to finding such a discrete function (8) for which the average indicator is T_{cp}, where

$$T_{cp} = \frac{1}{n}\sum_{i=1}^{n} T_{2i} \quad (10)$$

would reach an extremum. In this case, we assume the indicator remains constant $\Delta T_{ш}$across all sectors. If we accept , $n \to \infty$we can move from the discrete model discussed above to the continuous star-shaped DFOS model . In this case, the research problem can be formulated as follows : Calculate the optimal continuous function

$$t = f(\alpha) \quad (11)$$

at which the objective functional F_0formed on the basis of expression (1) as an optimization criterion would reach an extremum, where

$$F_0 = \frac{1}{\Delta\alpha}\int_{\alpha_1}^{\alpha_2} C_3\alpha[1 - \exp(-C_4 t)]d\alpha \quad (12)$$

Where

$$\Delta\alpha = \alpha_2 - \alpha_1 \quad (13)$$

$$C_3 = \frac{E_{inc}A_{inc}}{hA}$$

$$C_4 = \frac{hA}{cm}$$

To solve the formulated problem, we impose the following restrictive condition on function (11):

$$\int_{\alpha_1}^{\alpha_2} f(\alpha)d\alpha = C_5;\ C_5 = const \quad (14)$$

Constraint condition (11) stems from the need for efficient distributed measurements. Taking into account expressions (12) and (14), we formulate the objective functional for variational optimization F_0as follows:

$$F_0 = \int_{\alpha_1}^{\alpha_2} \frac{1}{\Delta\alpha}\left[C_3\alpha\left[1 - \exp\left(-C_4 f(\alpha)\right)\right]\right]d\alpha - \lambda\left[\int_{\alpha_1}^{\alpha_2} f(\alpha)d\alpha - C_3\right] \quad (15)$$

Where λ-Lagrange multiplier; $\lambda = const$.

To calculate the optimal form of the function $f(\alpha)$, i.e. $f(\alpha)_{opt}$Let's use Euler's method, according to which the solution to problem (12) must satisfy the following condition

$$\frac{d\{C_3\alpha[1 - \exp(-C_4 f(\alpha))] - \lambda f(\alpha)\}}{df(\alpha)} = 0 \quad (16)$$

From expression (16) we find

$$f(\alpha) = \frac{1}{C_4}\ln\left(\frac{C_3 C_4 \alpha}{\lambda}\right) \qquad (17)$$

When solving (17) F_0it reaches a maximum, which is easy to verify using the Lagrange criterion. We have

$$\frac{d^2\{C_4\alpha[1-\exp(-C_4 f(\alpha)) - \lambda f(\alpha)]\}}{d(f(\alpha))^2} = -C_4 \exp(-C_4 f(\alpha))$$

The negative sign obtained as a result of calculating the second derivative of the integrand in (12) with respect to the desired function shows that the functional F_0reaches a maximum when solving (17). Let us calculate this maximum. Taking into account expressions (12) and (17), we obtain

$$F_0 = \int_{\alpha_1}^{\alpha_2} \frac{C_3\alpha}{\Delta\alpha}\left[1 - \exp\left(-\ln\frac{C_3C_4\alpha}{\lambda}\right)\right]d\alpha = \int_{\alpha_1}^{\alpha_2} \frac{C_3\alpha}{\Delta\alpha}\left[1 - \frac{\lambda}{C_3C_4\alpha}\right]d\alpha = \frac{C_3(\alpha_2^2-\alpha_1^2) - \frac{\lambda}{C_4}(\alpha_2-\alpha_1)}{\Delta\alpha} \qquad (18)$$

From expression (18) we obtain

$$T_{cp} = C_3(\alpha_2+\alpha_1) - \frac{\lambda}{C_4} \qquad (19)$$

In the case of using one diametrically located measuring instrument, $t \to \infty$from (1) we $T_0 = 0$obtain

$$T_2 = C_3\alpha \qquad (20)$$

We define the gain in determining the temperature as

$$\gamma = \frac{T_{cp}}{T_2} = \frac{\alpha_2+\alpha_1}{\alpha} - \frac{\lambda}{C_3C_4\alpha}$$

when $\alpha_2 = \alpha$we have

$$\gamma = 1 + \frac{\alpha_1}{\alpha} - \frac{\lambda}{C_3C_4\alpha}$$

Thus, $\frac{\lambda}{C_3C_4} \ll \alpha_1$we get a win$\gamma = 1 + \frac{\alpha_1}{\alpha}$ i.e. we $\alpha_1 \to \alpha$get a double win $\gamma = 2$.

Accordingly, in the case of equal noise values in the star-shaped structure of the meter and in a system consisting of one pair of diametrically laid cables, a twofold gain in the signal-to-noise ratio can be achieved in the area under study.

3. Conclusion

The possibility of optimizing the star-shaped structure of a measuring system for assessing solar radiation in radial directions from the center of a circular study area has been formulated and resolved. It has been determined that a star-shaped structure for measuring temperature in radial sectors of a circular area can achieve a twofold improvement in signal-to-noise ratio compared to the use of diametrically positioned fiber optic cables.

References

[1] Guemes A., Fernandez-Lopez A., Lozano A. Fiber optic distributed sensing // STO-EN-AVT-220.

[2] Magalhaes R., Garcia-Ruzi A., Martins HF, Margulis W. et al. Distributed detection of optical radiation using chirped-pulse phase-sensitive optical time domain reflectometry // 26th international conference on optical fiber sensors. OSA 2018.

[3] Flores-Bravo JA, Lazaro J, Cuadrado C, et al. Applications of multipoint distributed fiber optic sensors for monitoring in critical systems // XL conference on design of circuits and integrated systems. 26 November. 2025.

[4] Costa L., Martin-Lopez S., Gonzalez- Herraez M., Martins HF Long-range distributed solar irradiance sensing using optical fibers // Sensors. 2020. 20.

[5] Paulescu M., Paulescu E. Short-term forecasting of solar irradiance // Renev . Energy. 2019. 143. 985-994.

[6] Joshi, B.; Kay, M.; Copper, J. K.; Sproul, A.B. Evaluation of solar irradiance forecasting skills of the Australian Bureau of Meteorology's ACCESS models. Sol. Energy 2019, 188, 386–402.

[7] Kurashima, T.; Horiguchi, T.; Tateda , M. Distributed-temperature sensing using stimulated Brillouin scattering in optical silica fibers. Opt. Lett. 1990, 15, 1038–1040.

[8] Mikhailov, S.; Zhang, L.; Geernert, T.; Bergmans , F.; Thevenaz , L. Distributed hydrostatic pressure measurement using phase OTDR in a highly birefringent photonic crystal fiber. J. Lightwave Technol. 2019, 37, 4496–4500.

[9] Zhou, L.; Wang, F.; Wang, X.; Pan, Y.; Sun, Z.; Hua, J.; Zhang, X. Distributed strain and vibration sensing system based on phase-sensitive OTDR. IEEE Photonics Technol. Lett. 2015, 27, 1884–1887.

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