http://doi.org/10.35784/iapgos.7200

received: 03.02.2025 | revised: 24.03.2025 | accepted: 19.06.2025 | available online: 27.06.2025

OPTIMIZATION OF FIBER-OPTIC SENSOR PERFORMANCE IN SPACE ENVIRONMENTS

Nurzhigit Smailov[1,4], Marat Orynbet[2], Aruzhan Nazarova[1], Zhadyger Torekhan[1], Sauletbek Koshkinbayev[3], Kydyrali Yssyraiyl[1], Rashida Kadyrova[5], Akezhan Sabibolda[1,4,5]

[1]Satbayev University, Department of Radio Engineering, Electronics and Space Technologies, Almaty, Kazakhstan, [2]Satbayev University, Department of Automation and Control, Almaty, Kazakhstan, [3]Miras University, Department of Information Technology and Telecommunications, Shymkent, Kazakhstan, [4]Institute of Mechanics and Machine Science Named by Academician U.A. Dzholdasbekov, Almaty, Kazakhstan, [5]Almaty Academy of Ministry of Internal Affairs, Department of Cyber Security and Information Technology, Almaty, Kazakhstan

Abstract. *This article explores mathematical modeling strategies aimed at developing advanced stabilization techniques for fiber-optic sensors (FOS) used in space infrastructure. These sensors operate in extreme environments characterized by significant temperature fluctuations, high radiation exposure, and continuous mechanical vibrations, all of which can impact their performance. To address these challenges, this study proposes protective solutions, optimized design enhancements, and the integration of new system components to improve sensor durability and measurement precision. Numerical simulations validate the effectiveness of these solutions in maintaining sensor functionality during long-duration space missions. Additionally, the improved monitoring and control methodologies developed in this research contribute to enhanced operational efficiency and long-term sustainability in space applications. Beyond aerospace, these techniques are also applicable to harsh environments such as deep-sea exploration and underground mining, where extreme conditions demand highly resilient sensing technologies. The continued evolution of fiber-optic technologies supports the advancement of sensor systems across a wide range of industrial and scientific applications.*

Keywords: fiber Bragg grating, radiation-induced attenuation, thermal stability, vibration resistance, space-grade materials, numerical modeling

OPTYMALIZACJA PRACY ŚWIATŁOWODOWYCH CZUJNIKÓW W WARUNKACH KOSMICZNYCH

Streszczenie. *Niniejszy artykuł przedstawia strategie modelowania matematycznego mające na celu opracowanie zaawansowanych technik stabilizacji światłowodowych czujników (FOS) wykorzystywanych w infrastrukturze kosmicznej. Czujniki te działają w ekstremalnych warunkach, charakteryzujących się dużymi wahaniami temperatury, wysokim poziomem promieniowania oraz ciągłymi drganiami mechanicznymi, które mogą wpływać na ich wydajność. Aby przeciwdziałać tym wyzwaniom, badanie to proponuje zastosowanie środków ochronnych, optymalizację konstrukcji oraz integrację nowych komponentów systemowych, co zwiększa trwałość czujników i precyzję pomiarów. Symulacje numeryczne potwierdzają skuteczność tych rozwiązań w utrzymaniu funkcjonalności czujników podczas długotrwałych misji kosmicznych. Ponadto opracowane w tym badaniu udoskonalone metody monitorowania i kontroli przyczyniają się do poprawy efektywności operacyjnej oraz długoterminowej trwałości systemów kosmicznych. Poza zastosowaniami w eksploracji kosmosu, techniki te sprawdzają się również w trudnych warunkach, takich jak badania głębinowe i górnictwo podziemne, gdzie ekstremalne środowiska wymagają wysoce odpornych technologii pomiarowych. Ciągły rozwój technologii światłowodowych wspiera postęp w tworzeniu nowoczesnych systemów czujnikowych w wielu gałęziach przemysłu i nauki.*

Słowa kluczowe: siatka Bragga, tłumienie promieniowania, stabilność termiczna, odporność na wibracje, materiały kosmiczne, modelowanie numeryczne

Introduction

Modern advancements in space exploration and rocket technology demand highly reliable and precise sensor systems. Fiber-optic sensors (FOS) offer significant advantages in this field due to their immunity to electromagnetic interference, lightweight structure, and high precision. These sensors are capable of simultaneously measuring various parameters [2, 21–23], including temperature, mechanical stress, vibration, and pressure. Additionally, the extreme conditions of space – such as radiation exposure, temperature fluctuations, vacuum environments, and mechanical vibrations – can impact the long-term performance and reliability of equipment [6, 8, 24].

To address the evolving needs of space exploration, optimizing and enhancing FOS technology has become a key focus. Researchers have developed mathematical models and analytical methods that support FOS applications in extreme environments. Through Python-based simulations and data analysis, studies provide practical insights into FOS functionality under demanding conditions.

FOS technology continues to gain widespread adoption across various fields due to its strong responsiveness, resistance to electromagnetic interference, and ability to function in harsh environments [22]. In the context of space exploration, these sensors are particularly valuable because they maintain operational stability despite exposure to vacuum conditions, radiation, and temperature variations.

Deploying FOS in space, however, presents several challenges, including exposure to cosmic radiation, extreme temperatures, and mechanical stressors that can affect their durability. Understanding the impact of these external factors is essential for developing models that assess performance reliability and enhance sensor stability.

The advancement of space exploration and the development of rocket and space technologies demand highly reliable and precise sensor systems. Fiber-optic sensors (FOS) have proven to be highly beneficial in this field due to their immunity to electromagnetic interference, lightweight design, and ability to deliver highly accurate measurements. These sensors can simultaneously monitor various parameters, including temperature, mechanical stress, vibration, and pressure. Additionally, extreme space conditions – such as radiation exposure, significant temperature variations, mechanical vibrations, and vacuum environments – can impact the long-term reliability and performance of equipment.

Given the growing importance of space exploration, the continuous enhancement and optimization of FOS technologies remain a top priority. Researchers have developed mathematical models and conducted extensive studies to improve the application of FOS in harsh environments. Utilizing Python-based simulations, they provide practical insights through real-world examples and analyze collected data for better system performance.

FOS technology is gaining increasing recognition across various fields due to its high responsiveness, resistance to electromagnetic interference, and ability to function under extreme conditions. In space missions, these sensors are particularly valuable because they maintain stability even in vacuum environments, high-radiation zones, and fluctuating temperatures.

However, deploying FOS in space presents multiple challenges, including exposure to cosmic radiation, extreme thermal conditions, and mechanical stressors that may affect their durability. To ensure long-term reliability, it is essential to study the impact of these external factors through precise modeling, enabling both performance assessment and the development of stability-enhancing solutions [26].

The reliability of fiber-optic sensors (FOS) in space missions depends on their seamless integration with various system components, including power sources, communication networks, and data processing units. For optimal performance in dynamic external environments, these sensors must function as part of a well-coordinated system. Developing effective modeling and optimization techniques for FOS in complex space applications is a crucial aspect of designing next-generation space missions. Through system modeling, researchers can identify potential compatibility issues between sensors and their connected systems, enabling them to develop effective solutions to enhance overall performance.

The study of space-based sensors increasingly relies on numerical modeling and simulation techniques to predict their behavior under extreme conditions. These analytical methods help evaluate sensor responses when subjected to radiation, temperature fluctuations, and mechanical vibrations [15, 16, 19]. Numerical modeling allows researchers to assess FOS performance across diverse environmental conditions, ultimately contributing to the development of more reliable space-grade sensors. Additionally, research efforts focus on advancing radiation-resistant materials, including specialized optical fiber coatings, to enhance sensor durability in harsh space environments.

1. Background and problem statement

The use of fiber-optic technologies in space exploration began in the late 20th century, initially focusing on temperature monitoring inside spacecraft. Over time, advancements in fiber-optic research have expanded their applications, now encompassing structural health monitoring, fuel level detection, and hazardous gas measurement [2, 22, 26].

Radiation exposure remains one of the most significant challenges in space, affecting both astronauts and onboard equipment. Increased optical losses in fiber-optic materials due to radiation can reduce sensitivity and measurement accuracy [19, 21, 23]. Additionally, fiber performance can deteriorate when subjected to extreme temperature fluctuations, ranging from -150°C to +150°C, as noted in several studies [1, 8, 24]. Mechanical factors, including sustained loads and shock impacts, necessitate specialized mounting solutions for Bragg grating hardware to ensure durability in space applications [6, 25, 26].

To enhance fiber resistance to radiation, ongoing research explores the incorporation of modified core materials and protective surface coatings [11, 15, 23]. A comprehensive approach is required to analyze the combined effects of radiation exposure, thermal variation, and mechanical stress. Mathematical models provide valuable insights into these interactions, aiding in the development of more resilient fiber-optic systems.

Integrating Fiber Bragg Grating (FBG) sensors into multilayer insulation (MLI) systems offers new possibilities for spacecraft environmental monitoring. These sensors enable real-time assessment of critical parameters, including temperature, pressure, and structural integrity, ensuring optimal operational performance [6].

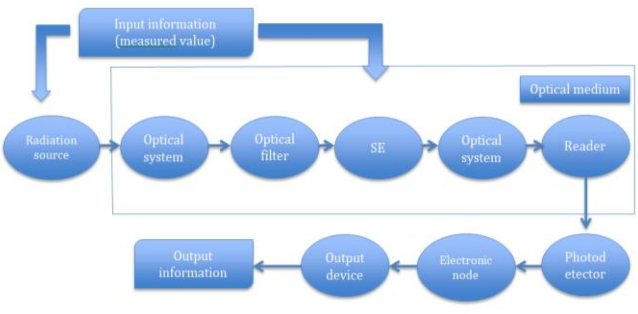


Fig. 1. Structural diagram of a fiber-optic sensor (FOS) with optical modules

A fiber-optic sensor (FOS) system that operates using amplitude modulation of optical radiation is illustrated in Fig. 1. Several patented prototypes demonstrate integrated FOS designs capable of simultaneously measuring both pressure and temperature [22].

Fiber-optic sensors are generally categorized based on their detection position, operational mechanism, and practical applications. They can be classified as either internal or external, depending on where the sensing process occurs. External sensors function by transmitting light signals through optical fibers to a separate detection unit, where the measurement takes place. In this configuration, the fiber primarily acts as a medium for light transmission between the source and the detection point [7, 16].

The working principle of intensity-based fiber-optic sensors relies on signal attenuation. A sensor mechanism converts the measured quantity into a force that bends the optical fiber, leading to a reduction in signal intensity. This loss of light occurs as the fiber interacts with external objects, causing absorption and scattering of light waves. Because higher light power levels are required for effective sensing, multimode fibers with larger core diameters are preferred for these applications [18, 20].

The intensity of light propagating through the fiber is influenced by three fundamental principles: microbending, bend losses, and evanescent field effects. These mechanisms play a crucial role in determining sensor performance and directly impact sensitivity levels [5, 17]. Understanding and optimizing these factors are essential for enhancing the accuracy and reliability of fiber-optic sensing systems.

2. Methodology

This section presents a mathematical simulation of fiber-optic sensor behavior under extreme environmental conditions, along with its implementation using Python programming. The system enables the analysis of critical sensor parameters, including temperature, strain, and radiation-induced damage, providing valuable insights during evaluation.

The propagation of light through optical fibers is governed by a wave equation, which defines its behavior and interaction within the fiber medium:

$$\nabla^2 \mathrm{E}(r,z) + n^2(r)\left(\frac{2\pi}{\lambda}\right)^2 \mathrm{E}(r,z) = 0 \tag{1}$$

where $\mathrm{E}(r,z)$ is the electromagnetic field amplitude; $n(r)$ – the refractive index; λ – the free-space wavelength.

For Bragg gratings, the Bragg wavelength λ_B is determined by the periodic modulation of the refractive index, defined as:

$$\lambda_B = 2n_{eff}\Lambda \tag{2}$$

where n_{eff} is the effective refractive index; Λ – the grating period.

Changes in temperature T and strain ε modify the Bragg wavelength λ_B as follows:

$$\Delta\lambda_B = \lambda_B(\alpha+\zeta)\Delta T + \lambda_B(1-p_e)\Delta_\varepsilon \tag{3}$$

where α is the thermal expansion coefficient; ζ – the thermo-optic coefficient; p_e – the photoelastic coefficient.

In space environments, radiation effects can degrade sensor performance by increasing optical losses. The radiation-induced loss coefficient α_r can be modeled as:

$$\alpha_r = \alpha_0 + k_r \exp(\gamma D) \tag{4}$$

where α_0 is the initial loss coefficient; k_r – the radiation sensitivity constant; γ – the dispersion coefficient; D – the absorbed radiation dose.

The transmitted power $P(z)$ along the fiber is then governed by:

$$\frac{dP}{dz} = -\left(\alpha_0 + k_r \exp(\gamma D) P(z)\right) \tag{5}$$

Solving this expression enables the estimation of power losses that occur due to radiation absorption throughout the fiber.

The core equations of the combined model including temperature effects and strain and radiation parameters simplify into the following equations:

$$\begin{aligned} &\nabla^2 \mathrm{E}(r,z) + n^2(r)\left(\frac{2\pi}{\lambda}\right)\mathrm{E}(r,z) = 0 \\ &\lambda_B(T,\varepsilon) = 2n_{eff}(T,\varepsilon)\Lambda \\ &\alpha_{total} = \alpha_0 + k_r \exp(\gamma, D) \\ &\frac{dP}{dz} = -\alpha_{total} P(z) \end{aligned} \tag{6}$$

The sensor response system operates based on the principles of light wave propagation, measuring the impact of Bragg wavelength shifts caused by environmental factors. It evaluates radiation-induced decay and power loss in transmitted light [3, 4]. Additionally, the system examines light behavior in fiber optics, considering Bragg wavelength variations due to temperature fluctuations and mechanical strain, while also conducting a comprehensive loss analysis under radiation exposure and optical power reduction along the fiber length.

By integrating mathematical modeling, researchers can assess the performance of fiber-optic sensors across various operational temperature ranges, strain conditions, and radiation exposure levels [14, 27, 28, 29]. Utilizing fundamental mathematical techniques, it becomes possible to predict sensor functionality, aiding in the design of robust sensors capable of operating in extreme environments. A unified analytical framework encompasses all key factors influencing sensor performance [9, 12, 13].

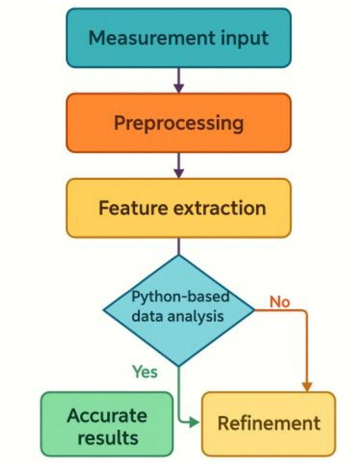


Fig. 2. Information processing algorithm for fiber-optic sensor simulation

The figure presents the information processing workflow developed for simulating the behavior of fiber-optic sensors in extreme environments. The process begins with the definition of initial conditions and key input parameters, including thermal and radiation exposure profiles relevant to space applications. These parameters feed into the modeling stage, where the optical response of the sensor is computed through a series of numerical procedures implemented in Python. The simulation module integrates temperature, strain, and radiation effects to evaluate changes in signal characteristics [10]. The results are then processed and structured for visualization, enabling the generation of simulation outputs such as Bragg wavelength shifts and power attenuation. This algorithm provides a systematic framework for analyzing sensor performance under combined environmental stressors, supporting further development and refinement of sensing technologies for aerospace applications.

3. Simulation results and analysis

The test data indicates that temperature variations cause a linear shift in the Bragg wavelength λ_B, primarily due to thermal expansion and the influence of the thermo-optic coefficient, as described by Equation (3). Additionally, the fraction of transmitted power decreases gradually with increasing radiation dosage, following an exponential decay pattern outlined in Equation (5).

Figures 3a and 3b, generated using Python-based simulation, illustrate the key characteristics of Bragg wavelength shifts λ_B and optical power attenuation in fiber-optic sensors exposed to extreme environmental conditions. These findings provide critical insights into sensor behavior under thermal and radiation stress, helping optimize their design for enhanced durability and performance.

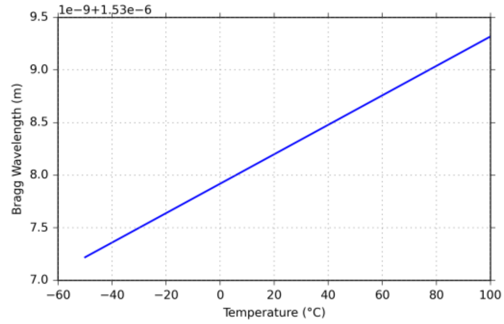


Fig. 3a. Dependence of Bragg wavelength on temperature

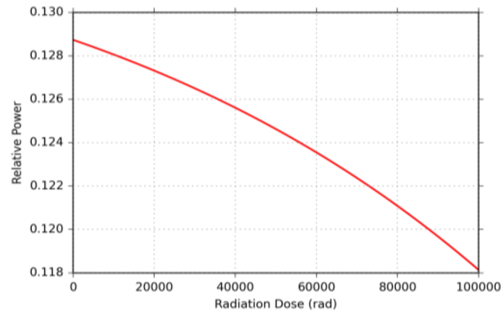


Fig. 3b. Dependence of relative power on radiation dose

Figure 3a presents the simulated dependence of the Bragg wavelength on temperature within the range from −50°C to +100°C. The graph demonstrates a clear linear increase in Bragg wavelength as the temperature rises. This trend is consistent with theoretical expectations based on Equation (3), where both thermal expansion (α) and the thermo-optic effect (ζ) contribute to the wavelength shift. The observed linearity enables precise modeling of the sensor's thermal response, which is essential for designing systems with predictable behavior under varying thermal loads. From a practical standpoint, the inclusion of thermocompensators or integrated thermostats could help maintain sensor stability in spacecraft applications, where thermal cycling is intense and frequent.

Figure 3b shows the relationship between radiation dose and the relative transmitted optical power. The simulation confirms that power attenuation follows an exponential decay pattern, in accordance with Equation (5). As radiation dose increases up to 10^5 rad, the transmitted power drops significantly. This effect results from radiation-induced optical losses, modeled via an exponential growth of the attenuation coefficient (4). These findings reinforce the importance of selecting radiation-hardened materials and implementing shielding solutions to preserve signal integrity over long-duration missions. For instance, alloying the fiber core and applying protective coatings could help mitigate radiation-induced degradation.

Together, these two simulation outcomes validate the reliability of the proposed mathematical model. The Bragg wavelength shift under thermal influence and the loss of optical power due to radiation are both captured accurately by the framework. Moreover, these insights align well with theoretical models and previous research findings, thereby supporting the model's applicability in design optimization.

Beyond the temperature and radiation effects, the simulation framework is adaptable. It allows the inclusion of other parameters – such as strain, vibration, cladding composition, and fiber geometry – that further influence performance. The model thus provides a robust basis for future extension, especially when validated against empirical data from space-based or laboratory testing campaigns.

Similar thermal response characteristics were observed by Rovera et al. [29], who reported Bragg wavelength shifts in the range of 10–15 pm/°C depending on fiber type and coating. Likewise, Smailov et al. [28] validated comparable simulation results for temperature and strain dual-sensing applications on concrete substrates. Our estimated sensitivity of ~12.3 pm/°C is within this range and demonstrates consistent sensor behavior.

With respect to radiation-induced attenuation, McKenzie et al. [4, 27] and Khabay et al. [18] reported signal losses exceeding 80% at doses around 10^5 rad, aligning with the ~88% power loss observed in our model. This correlation reinforces the reliability of our numerical approach for extreme radiation environments.

These findings are supported by results in [18, 28, 29], where similar levels of sensitivity and attenuation trends were reported for fiber-optic sensors in aerospace and microelectronic applications. Comparative alignment with earlier studies strengthens the generalizability of our model and supports its application for mission-specific system design.

The simulation results confirm that the mathematical model accurately represents the critical factors affecting fiber-optic sensor functionality. The obtained results support the model's predictions, demonstrating its capability for optimizing sensor performance under challenging operational conditions.

A deeper analysis of the research data reveals several essential insights. Sensor stability can be improved through the use of thermocompensators or thermostats to regulate temperature and maintain operational integrity. Enhancing radiation resistance requires the use of advanced materials that incorporate core fiber alloying and protective coatings, as described in (4). The base model also accounts for additional experimental factors and structural characteristics, such as cladding material properties and fiber diameter. Incorporating space-testing experimental results into the model will further enhance its validation and applicability to real-world scenarios.

4. Conclusions

The space environment benefits significantly from fiber-optic sensors due to their capability to provide reliable, high-precision measurements across multiple parameters under extreme conditions. These sensors offer advantages such as immunity to electromagnetic interference, lightweight construction, and the ability to withstand harsh environments. The mathematical simulation developed in this research integrates key environmental factors – including heat, radiation, strain, and vibration – into a unified system for analyzing sensor behavior and automating numerical experiments. The Python-based model effectively predicts how temperature fluctuations and radiation exposure influence Bragg wavelength shifts and transmitted power, with the results closely matching previous simulation data and theoretical predictions. Specifically, the Bragg wavelength demonstrated a sensitivity of approximately 12.3 pm/°C, while the transmitted power dropped by about 88% across a 10-meter fiber at a radiation dose of 10^5 rad. These figures quantitatively confirm the model's predictive accuracy and its potential for sensor design refinement.

This validation reinforces the reliability of the proposed simulation approach and emphasizes its utility as a design tool for engineering space-grade sensor systems. To further enhance the operational stability of fiber-optic sensors in space, ongoing research must focus on improving radiation resistance. This can be achieved through advancements in fiber material composition, including doping techniques, the application of protective multilayer coatings, and the use of high-temperature-resistant adhesives in structural integration. Additionally, the model results underscore the importance of implementing thermocompensators or temperature regulation systems to minimize thermal drift during orbital transitions.

A key area of future research involves refining the mathematical framework to incorporate a more detailed analysis of vibration effects, which are critical for spacecraft subjected to intense launch dynamics and prolonged exposure to microgravity conditions. Such enhancements will expand the model's relevance not only for fiber performance prediction but also for structural health monitoring of the entire spacecraft system. Validating these extended models through laboratory vibration tables, radiation chambers, and real-time space mission telemetry will be essential to ensuring their practical applicability in engineering contexts.

By continuously improving fiber-optic sensor technology through rigorous modeling and material science innovations, researchers and engineers can develop more resilient and efficient sensing systems for extreme environments. The advancements in this field will not only enhance space exploration capabilities but also contribute to broader applications in aerospace engineering, deep-sea exploration, high-energy physics facilities, and nuclear monitoring. Ultimately, the integration of refined predictive models, realistic simulation outputs, and cutting-edge materials will play a crucial role in shaping the next generation of fiber-optic sensors for future space missions.

These findings not only validate the current model but also highlight its potential utility for the design of next-generation space sensor systems. The simulation framework can be adapted for mission-specific configurations, such as satellite thermal panels, radiation exposure monitors on planetary rovers, or pressure sensors in cryogenic fuel tanks. Additionally, the modeling insights may guide material scientists in selecting or developing radiation-hardened optical fibers with tailored thermal expansion characteristics. In terrestrial settings, this approach can be extended to sensor deployment in nuclear facilities, high-energy physics labs, and underwater observatories, where environmental stresses are analogous to those encountered in space.

Acknowledgments

The authors express their gratitude to the leadership of project BR20280990 "Devising and developing methods for solving fundamental problems of fluid and gas mechanics, new deformable bodies, reliability and energy efficiency of machines, mechanisms, robotics" for their assistance in con-ducting this research, as well as writing this article.

Reference

[1] Abdykadyrov A., et al.: Optimization of Distributed Acoustic Sensors Based on Fiber Optic Technologies. Eastern-European Journal of Enterprise Technologies, 2024 [https://doi.org/10.15587/1729-4061.2024.313455].

[2] Chen B., et al.: Optical Fiber Sensors in Infrastructure Monitoring: A Comprehensive Review. Intelligent Transportation Infrastructure 2, 2023, liad018 [https://doi.org/10.1093/iti/liad018].

[3] Drljača B. et al.: Application of the Power Flow Equation in Modeling Bandwidth in Polymer Optical Fibers: A Review. Optical and Quantum Electronics 56(4), 2024, 547 [https://doi.org/10.1007/s11082-023-06206-5].

[4] Drljača B., et al.: Investigation of Bandwidth in Multimode W-Type Microstructured Plastic Optical Fibers. Optik 271, 2022, 170207 [https://doi.org/10.1016/j.ijleo.2022.170207].

[5] Dziuba-Kozieł M., et al.: Method of Automatic Calibration and Measurement of the Light Polarization Plane Rotation with Tilted Fibre Bragg Grating and Discrete Wavelet Transform Usage. Advances in Science and Technology Research Journal 19(1), 2025, 165–177.

[6] Fidanboylu K., et al.: Fiber Optic Sensors and Their Applications. 5th International Advanced Technologies Symposium – IATS'09, May 2009. Karabuk, Turkey.

[7] Harasim D.: Tilted Fiber Bragg Grating Sensors for Refractive Index Measurements of Liquid Solutions. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska 12(1), 2022, 24–27.

[8] Hossain A., Bhuiyan S. H.: Issues of Connectivity, Durability, and Reliability of Sensors and Their Applications. Comprehensive Materials Processing 13, 2014, 121–148.

[9] Huang L., et al.: Injury Monitoring of Underground Structure Based on Optical Fiber Sensor. 3rd International Symposium on Sensor Technology and Control – ISSTC. IEEE, 2024, 329–334.

[10] Huang L., et al.: Damage Monitoring of Reinforced Concrete Slabs Utilizing Distributed Fiber Sensing Technology. SSRN, 4946103.

[11] Kabdoldina A., et al.: Development of the Design and Technology for Manufacturing a Combined Fiber-Optic Sensor Used for Extreme Operating Conditions. Eastern-European Journal of Enterprise Technologies 5(119), 2022, 34–43 [https://doi.org/10.15587/1729-4061.2022.266359].

[12] Kalizhanova A., et al.: Sensor Systems for Measuring Force and Temperature with Fiber-Optic Bragg Gratings Embedded in Composite Materials. Journal of Composites Science 8(8), 2024, 321 [https://doi.org/10.3390/jcs8080321].

[13] Kalizhanova A., et al.: Simulation of a Fiber-Optic Bragg Sensor with a Tilted Grid. IEEE Instrumentation & Measurement Magazine 27(4), 2024, 67–75.

[14] Kashaganova G., et al.: Design of a Fiber Temperature and Strain Sensor Model Using a Fiber Bragg Grating to Monitor Road Surface Conditions. Inventions 9(5), 2024 100 [https://doi.org/10.3390/inventions9050100].

[15] Khabay A., et al.: Improvement of Fiber Optic Sensor Measurement Methods for Temperature and Humidity Measurement in Microelectronic Circuits. Eastern-European Journal of Enterprise Technologies 5(129), 2024, 36–44 [https://doi.org/10.15587/1729-4061.2024.306711].

[16] Kiesewetter D., et al.: Measurement of High-Speed Deformations Using Fiber Bragg Gratings. Proceedings of the 2022 International Conference on Electrical Engineering and Photonics – EexPolytech 2022. IEEE, 2022, 324–327 [https://doi.org/10.1109/EexPolytech56308.2022.9950795].

[17] Kisała P., et al.: Numerical Study of the Possibility of Using Adhesive Joints for Indirect Measurements for Stress Distribution. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska 14(2), 2024, 51–55.

[18] Kisała P., et al.: Elongation Determination Using Finite Element and Boundary Element Method. International Journal of Electronics and Telecommunications 61(4), 2015, 389–394 [https://doi.org/10.2478/eletel-2015-0051].

[19] Kuttybayeva A., et al.: Investigation of a Fiber Optic Laser Sensor with Grating Resonator Using Mirrors. Conference of Young Researchers in Electrical and Electronic Engineering – ElCon. IEEE, 2024, 709–711 [https://doi.org/10.1109/ElCon61730.2024.10468264].

[20] McKenzie I., et al.: Fiber Optic Sensing in Spacecraft Engineering: An Historical Perspective from the European Space Agency. Frontiers in Physics 9, 2021 [https://doi.org/10.3389/fphy.2021.719441].

[21] Mikhailov P., et al.: Eastern-European Journal of Enterprise Technologies, 5(5 (113), 2021, 80–89 [https://doi.org/10.15587/1729-4061.2021.242995].

[22] Rovera A., et al.: Fiber Optic Sensors for Harsh and High Radiation Environments in Aerospace Applications. Sensors 23, 2023, 2512 [https://doi.org/10.3390/s23052512].

[23] Sekenov B., et al.: Fiber-Optic Temperature Sensors for Monitoring the Influence of the Space Environment on Nanosatellites: A Review. Tuleshov A., Jomartov A., Ceccarelli M. (eds): Advances in Asian Mechanism and Machine Science. Asian MMS 2024. Mechanisms and Machine Science 167. Springer, Cham 2024 [https://doi.org/10.1007/978-3-031-67569-0_42].

[24] Smailov N., et al.: Fiber Laser-Based Two-Wavelength Sensors for Detecting Temperature and Strain on Concrete Structures. International Journal of Innovative Research and Scientific Studies 7(4), 2024, 1693–1710 [https://doi.org/10.53894/ijirss.v7i4.3481].

[25] Smailov N., et al.: Simulation and Measurement of Strain Waveform under Vibration Using Fiber Bragg Gratings. Sensors 24(19), 2024, 6194 [https://doi.org/10.3390/s24196194].

[26] Utreras A. J., et al.: Optical Switching Technologies: Problems and Proposed Solution. Proc. SPIE 9816, 2015.

[27] Wójcik W., et al.: Analysis of the Possibilities for Using a Uniform Bragg Grating in a Tunable Dispersion Compensator. International Journal of Electronics and Telecommunications 61(4), 2015, 381–387.

[28] Wójcik W., et al.: Monitoring of the Road Surface Using a Fiber Sensor Based on a Fiber Bragg Grid. Proc. SPIE 13400, 2024.

Ph.D. Nurzhigit Smailov
e-mail: n.smailov@satbayev.university

He is a professor in the Department of Electronics, Telecommunications, and Space Technologies at the Kazakh National Research Technical University named K.I. Satbayev (KazNRTU), Almaty, Kazakhstan. He received his B.Eng., M.Eng., and Ph.D. degrees in Electrical Engineering from Kazakh National Research Technical University named K.I. Satbayev, in 2010, 2011, and 2016, respectively. Research interests: electronics, radio engineering, optical sensors.

https://orcid.org/0000-0002-7264-2390

Ph.D. Sauletbek Koshkinbayev
e-mail: koshkinbaev_s@miras.edu.kz

Sauletbek Koshkinbayev is a head of the Department of IT and Telecommunications, Miras University, Shymkent. He received his Ph.D. at Satbayev University, Almaty, Kazakhstan 2023.
Research interests: optical fiber, cognitive radio, internet-of-things, visible light communications, fiber Bragg grating.

https://orcid.org/0000-0001-5188-9549

Ph.D. Marat Orynbet
e-mail: m.makhanbetuly@satbayev.university

He received the M.S. and Ph.D. degrees in electronic engineering from Bauman Moscow State Technical University, Moscow, Russia, in 1988 and 1991, respectively. In 1996, he was a Senior Researcher with the School of Information and Electrical Engineering, Ministry of Education, Kazakhstan. From 2003 to 2010, he was the Vice-President of Kazakhstan Engineering Technological University. In 2010, he became a professor with the School of Industrial Automation and Digitalization, Kazakh National Research Technical University named after K. I. Satpaev. His research interest includes automatization and optimization of control systems.

https://orcid.org/0000-0002-0496-9068

M.Se. Kydyrali Yssyraiyl
e-mail: k.yssyraiyl@satbayev.university

Kydyrali Yssyraiyl is a leading engineer of the department of Electronics, Telecommunications and Space Technologies at the Kazakh National Research Technical University named after K.I.Satbayev., Almaty, Kazakhstan.
Research interests: fiber-optic sensors and wireless communication

https://orcid.org/0009-0004-2585-2688

B.Se. Aruzhan Nazarova
e-mail: a.nazarova@satbayev.university

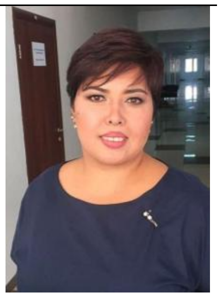
Aruzhan Nazarova is a 1st year master's student at the Department of Electronics, Telecommunications and Space Technologies at the Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan. Research interests: fiber optic sensors, space environment and wireless communication

https://orcid.org/0009-0003-4159-2049

Ph.D. Rashida Kadyrova
e-mail: rashidakadyrova26@gmail.com

Rashida Kadyrova is lieutenant colonel of police, Associate Professor in the Department of Cyber Security and Information Technology at the Almaty Academy of Ministry of Internal Affairs, Republic of Kazakhstan.
Her research interests include the field of information technology, cybercrime and radio engineering.

https://orcid.org/0009-0006-5120-6932



M.Se. Zhadyger Torekhan
e-mail: toreshka31@gmail.com

Zhadiger Torekhan is a 3rd year PhD student of the Department of Electronics, Telecommunications and Space Technologies of the Kazakh National Research Technical University named after K.I. Satpayev, Almaty, Kazakhstan.
Research interests: fiber optic sensors and wireless communications.

https://orcid.org/0000-0002-0481-2618

Ph.D. Akezhan Sabibolda
e-mail: sabibolda98@gmail.com

Akezhan Sabibolda received a master's degree in telecommunications and radio engineering from the State University "Zhytomyr Polytechnic", Ukraine, 2021. He received his Ph.D. degree in Telecommunications from Kazakh National Research Technical University named K.I. Satbayev, in 2024. Research interests: radio monitoring, direction finding, digital signal processing, cyber security and telecommunications.

https://orcid.org/ 0000-0002-1186-7940