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## INTEGRATION OF LASER AND OPTO-GALVANIC METHODS IN ENVIRONMENTAL MONITORING SYSTEMS OF TECHNOGENIC FACILITIES

*The current stage of development of the electric power, chemical, mechanical engineering, and printing industries is characterized by the extensive use of a wide range of resource components, including coal, oil, natural gas, paints and coatings, and polymers, which are marked by increased environmental aggressiveness. Highly intensive production operating modes, driven by market demands, lead to a significant growth in resource consumption within energy-intensive technological processes. This, in turn, results in increased concentrations of dust as well as harmful gaseous and liquid emissions released into the atmospheric and aquatic environments, causing an overall deterioration of environmental conditions. At the same time, real-time assessment of the environmental state is often complicated by the limited capabilities of data acquisition and processing using conventional measurement methods.*

*A considerable number of information and measurement systems, laboratory methods, and analytical instruments exist for determining the concentration of harmful emissions in the atmosphere, soils, and water bodies of ecosystems; however, most of these approaches are based on environmental sampling followed by laboratory analysis, which requires a certain amount of time. In technological systems, control and measurement devices and sensors are employed; nevertheless, they do not ensure the measurement of critical production process parameters during the stages in which pollutant flows are generated.*

*Typical examples include emissions of combustion products in boilers of thermal power plant units and municipal systems, as well as in construction, transport and aviation sectors, oil refining and gas industries, and chemical plants of both public and private ownership.*

*In this context, the problem of environmental monitoring—namely, the development of systems, structures, and sensors—is technically urgent and socially significant.*

*Accordingly, the development of information technologies for data acquisition in environmental monitoring of ecological media (atmosphere, water, and soils), based on opto-galvanic pollution control methods and laser remote sensing techniques for measuring the concentration of harmful gas emissions, combustion products, and dust, is highly relevant, as these technologies enable continuous monitoring of pollutant concentrations.*

*Key words: ecosystem, atmosphere, dust, control, lasers, environmental safety, sensors.*

### Introduction

Environmental monitoring of technogenic energy-active structures as well as industrial and printing enterprises under multifactor threat conditions is of critical importance. Threats such as power supply failures, fires, emissions of hazardous substances, explosions in technological units, accidents caused by loss of control over automated systems, and military actions lead to intensive contamination of the atmosphere, soils, and water bodies. Active technogenic impacts generate dust flows and emissions of harmful gases and liquids that significantly deteriorate the environmental state, creating adverse conditions for human life, public health, and society as a whole. These processes become particularly dangerous under wartime conditions, when the scale and intensity of environmental hazards increase substantially.

During armed conflicts, the ecological situation across the entire territory of the state becomes increasingly complex due to pollution of residential and natural environments by industrial waste, rocket fuel residues, and explosions of ammunition with

unknown chemical composition. Both combustion products and dust aerosols dispersed in the environment pose serious hazards, creating latent threats to public health.

#### Analysis of literature sources

The analysis of literary sources indicates a significant and steadily growing research interest in addressing environmental monitoring problems, particularly in the development of advanced information technologies for data acquisition, processing, and interpretation, as well as in the application of laser remote sensing methods and the analysis of measurement results. Modern environmental monitoring systems increasingly rely on integrated approaches that combine sensor technologies, information processing algorithms, and modeling tools to obtain reliable data on the state of environmental media. The application of laser remote sensing technologies for measuring the concentration levels of components in technological processes and environmental monitoring systems makes it possible to perform continuous real-time control. This capability forms the basis for timely emergency response, early detection of hazardous situations, and the implementation of preventive measures aimed at reducing environmental risks.

In studies [1,3,14,15,19], the authors focus on the development of information and measurement systems designed for monitoring technological processes and environmental conditions using both direct and indirect measurement methods. These works emphasize the importance of combining modern sensing technologies with effective data acquisition and processing procedures to improve the reliability and accuracy of measurements in scientific and applied research.

Study [2] substantiates modern approaches to statistical analysis and data processing based on optical research methods. Particular attention is given to the use of mathematical models and signal processing techniques for the interpretation of experimental data obtained from optical and laser measurement systems.

In works [4–8,11,12,16–18], the authors justify the use of expert systems and information technologies for planning and organizing measurement experiments. These approaches allow for the optimization of experimental procedures, the structuring of measurement data, and the improvement of decision-making processes in complex technical and environmental monitoring systems.

Monographs [9,10,13,20] consider methods for the integrated application of measurement systems and instruments aimed at enhancing the efficiency, accuracy, and reliability of measurements. These studies also present models and algorithms for data processing and interpretation that support situation assessment and decision-making in technical systems operating under uncertain and dynamically changing environmental conditions.

#### Materials and methods

The primary objectives of environmental assessment include determining the level of risk and safety of industrial activities, organizing comprehensive evaluation programs for production infrastructure facilities, verifying compliance with environmental legislation requirements, assessing the quality of natural resources, and forming a system of criteria for determining the environmental safety of facilities and the surrounding environment. In addition, the assessment of negative impacts of industrial and municipal structures on ecosystem conditions is performed, along with expert evaluation of programs for the implementation of new technologies from the standpoint of their environmental feasibility.

Monitoring of atmospheric air and water is essential for identifying pollutants and assessing their impact on structural corrosion, soil erosion processes, public health, vegetation development, ecosystem functioning, water quality in reservoirs and rivers, as well as the overall state of the atmosphere, particularly in large cities and industrial agglomerations.

The solution to the environmental monitoring problem is based on the development of laser sensing systems and opto-galvanic sensors, as well as on the formulation of methods for integrating galvanic effects from heterogeneous electrodes in liquid media. This problem is also addressed through the application of a system and information model of environmental sensing processes for evaluating the concentration levels of harmful substances in air, water, technological gases, and flue gases, as well as through the synthesis of measurement instrument structures.

The assessment of concentration levels within the sensing region of a technological process is based on information transformations of  $(C_k, \theta)$ :

$$C_k \xrightarrow{\leftarrow Z_C(\omega_M, P_L), t} Z_S(\omega_M, P_S(C_K, \alpha_S), t) \rightarrow U_{FII}(\omega_M, t, \theta_F(C_K)) \rightarrow \left| \frac{\hat{U}_{FII}}{\theta_F(C_K)} \right| \rightarrow \hat{C}_k \quad (1)$$

where  $C_k$  - component concentration level;  $Z_C, Z_S$  – modulating laser signal and the reflected signal;  $\omega$  – modulation frequency.

For monitoring liquid media, specialized transducers are required in which the process of measuring state parameters is based on the integration of methods and tools for data acquisition aimed at identifying informative features. Under such data acquisition procedures, it is necessary to apply standard (SI) evaluation methods based on:

- base SI units: L – length, M – mass, T – time, I – electric current,  $\theta$  – thermodynamic temperature, J – luminous intensity, N – amount of substance (mole);
- derived quantities:  $(\nu, F)$  – frequency of electric current oscillations, Q – electric charge,  $(V, \varphi, E)$  – electric potential, potential difference, electromotive force, P – electric power,  $(S, Q, P)$  – apparent, active, and reactive power, W – active electrical energy;
- parameters of electrical system components:  $(C, L, M)$  – capacitance, inductance, mutual inductance of elements,  $(R, g)$  – electrical resistance of conductive elements and physico-chemical components of the medium.

To verify measurement transducers, national and secondary standards stored at the National Scientific Center “Institute of Metrology” (Kharkiv) are used. However, for the evaluation of physico-chemical elements in solutions and the measurement of their concentrations, no established reference standards currently exist. This necessitates the development of indirect measurement methods, including appropriate hardware (sensor) and metrological support, as well as the selection of suitable base measures and calibration scales in accordance with the SI standard.

At the same time, to enhance the informational efficiency of measurement data, it is possible to integrate electrical, laser, and galvanic control methods of technological media. This integration enables high-quality data acquisition in accordance with algorithms of information transformation of system parameters.

The impurity concentration value is determined according to:

$$\hat{C}_K = K_n \hat{I}(C_K, E_{I1}, E_{I2}, \theta)_{S_C}; S_C = \left\{ S_{Ci} \Big|_{i=0}^m \right\} \quad (2)$$

where  $\hat{C}_K$  – estimated concentration value;  $\theta$  – environmental (medium) parameter;  $S_C$  – concentration scale of a specific substance, formed by calibrating the level  $C_{Ki}$  depending on the type of components in the solution within the interval

$$I(C_K) = [C'_K = \min, C_K^2 = \max | \theta_r] \quad (3)$$

Let us consider the structural scheme of the experimental stand designed for a comprehensive investigation of impurity concentration measurement methods in solutions, based on the combined use of laser sensing techniques and the generation of galvanic potential (Zn/Cu) by electrodes, in accordance with the following information diagram:

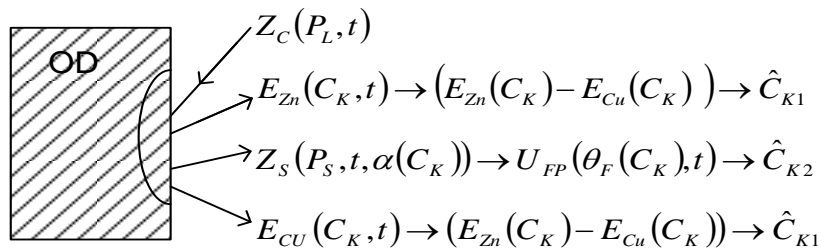


Fig. 1. Information diagram showing combined use of laser sensing techniques and the generation of galvanic potential (Zn/Cu) by electrodes

The specified requirements are satisfied by laser-based models of remote sensing of technological environments through optical windows installed in dust ducts.

#### Characteristics of concentration measurement sensors based on opto-galvanic effects

Let us present the schematic diagram of the measuring cell for impurity concentration assessment in solutions (Fig. 2).

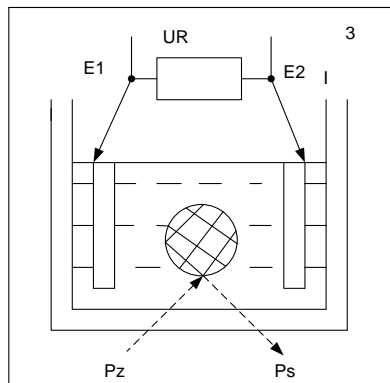


Fig. 2. Schematic diagram of laser beam interaction with a galvanic measurement cell

According to the experimental scheme, the variable parameters include:

- voltage, current, and radiation power of the semiconductor laser as a result of varying the stabilizer voltage, where  $V_{Ar}(U_S \in [0-5]B) \rightarrow V_{Ar}(P_L \in [0-P_{max}])$

- variation of impurity concentration dissolved in the liquid within the cuvette,  $C_{Kd} \in [C_{Kmin}, C_{Kmax}]$

Taking into account the formulated methodology for assessing impurity concentration levels, the following functional characteristics can be obtained:

- concentration level  $C_K \rightarrow U_{\Phi\Pi}(P_S(C_K))$  under conditions  $P_L \in \{P_i - const, P_i \in [0-500]mBm\}$

- photodetector output voltage as a function of concentration:  $U_{\Phi\Pi}(C_K) \rightarrow \{U_{\Phi\Pi}(P_S / C_K) / P_L - const, C_{Ki} - V_{ar}\}$

$U_{\Phi\Pi}(C_K) \rightarrow \{U_{\Phi\Pi}(P_S / C_K) / P_L - V_{ar}, C_{Ki} - const\}$   $I_{\Phi\Pi}(C_K) \rightarrow \{\varepsilon_{\Phi\Pi}(P_S / C_K) / P_L V_{ar}, C_K - const, R_A - const\}$

The construction of calibration characteristics with respect to impurity concentration is based on the corresponding functional dependence between measured electrical and optical parameters:  $U - (C_K) = \psi(P_L, C_K)$ ,

$I_{\Phi\Pi} = \psi(R_H)$ ,  $U_{\Phi\Pi} = \psi(R_N)$

An impurity concentration meter in solution with a logarithmic low-sensitivity scale under combined measurements  $(U_{\Phi\Pi}, I_{\Phi\Pi})$  is described by a system of equations that relate the impurity concentration level to voltage, current, potential, and current of the active electrodes  $(Cu, Zn)$  of the opto-galvanic sensor:

$$I_X = I_0 \exp(-\alpha(C_K)l_K), \alpha(C_K)l_K = \ln I_X - \ln I_0 \quad \alpha(C_K) = \frac{1}{l_K} [\ln U_{\Phi\Pi}(P_X) - \ln U_{\Phi\Pi}(P_0)] \quad P_{\Phi\Pi} = U_{\Phi\Pi}(I_{\Phi\Pi}) \cdot K_{U,P}$$

$$C_K = \psi(\alpha, V_K, l_K) \cdot \Delta U_{\Phi\Pi} (\ln U_X - \ln U_0) \left[ \frac{m\Omega}{cm^3} \right], U_{\Phi\Pi} = I_{\Phi\Pi} R_i \quad (4)$$

where  $C_K$  – impurity concentration;  $\alpha$  – reduced scattering coefficient;  $U_{\Phi\Pi}$  – photodetector voltage;  $(V_K, l_K)$  – volume and optical path length of the cuvette;  $Rg(A/D)$  – analog-to-digital data recorder;  $I_{\Phi\Pi}$  – photodetector current;  $R_i$  – load resistance.

Let us present the schematic diagram of the photodetector matrix cell for laser signal reception. The constructed voltage–power dependence obtained under laser illumination of the silicon photodetector matrix is shown in Fig. 3, where  $R_{\Phi\Pi}$  denotes the internal resistance of the photodetector,  $R_n$  is the load resistance of the photodetector, and  $PL$  represents the power of the photon flux generated by the laser.

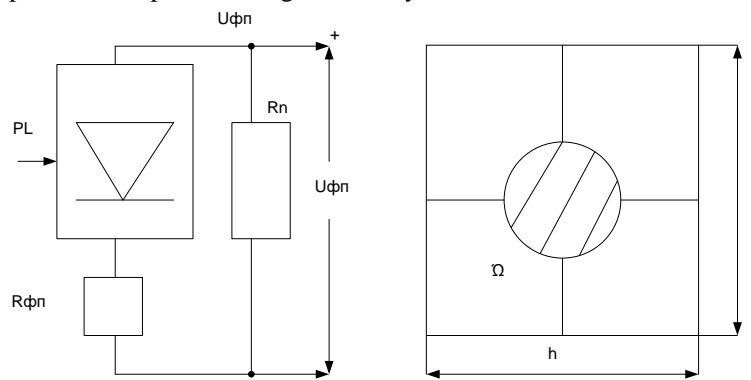


Fig. 3. Schematic diagram of the photodetector matrix

The analysis of photodetector characteristics  $\Psi(R_{oi}, PL, R_n)$  for the development of laser sensors shows that, for each normalized laser power level, it is necessary to measure the signal parameter values at the photodetector output—generated on the matrix under laser beam irradiation—at different values of the load resistance.

### Research results and their discussion

#### Opto-galvanic methods for monitoring pollution of the aquatic environment, soils, rivers and reservoirs with harmful substances from emissions of combustion products from thermal power plants and other enterprises

The research work carried out over the past fifteen years within the framework of the scientific and technical programs of the Center for Strategic Studies "Eco-bio-technical systems" performed both in the laboratory of laser sensing and at strategic level enterprises (Burshtyn TPP, Dobrotvir TPP, glassworks of the construction sector Bucha, Irpin, Kostopil, Rokytno) has shown the importance of creating integrated systems for environmental monitoring of the level of man-made pollution, both the environment and the entire ecosystem. The use of laser methods for sensing dust concentration and water pollution has shown their effectiveness and the creation of new types of sensors for information and measurement systems has led to new ideas for the development of sensors with integrated laser,

optoalvanic and ion-selective research methods. Accordingly, it was necessary to monitor the state of the environment under the influence of emissions of harmful substances by man-made systems into the atmosphere, soil and water reservoirs based on the combination of the latest methods and technologies.

To build opto-galvanic sensors, the method of combining galvanic effects from heterogeneous electrodes in a laser-activated liquid medium is used. The following parameters of the state and electrochemical quantum interaction of the liquid medium with the electrodes will be used as measuring parameters for estimating the concentration level:

$$(H_2O/C\kappa) \rightarrow \left( E_d(Zn)(H_2O) - E_d(Cu) \right) \rightarrow \left( (U_{1,2}/E_{11}, E_{12})/C\kappa \right) \rightarrow I((E_{11}, E_{12})/C\kappa) \quad (5)$$

$$(P_{ZL}) \rightarrow (\lambda_\varphi) \rightarrow \leftarrow (P_{SL}/C\kappa) \rightarrow U_{\Phi\Pi}(C\kappa)$$

According to the diagram, the controlling information parameters are the interelectrode voltage ( $U_{1,2}/C\kappa$ ), the current in the galvanic circuit ( $I(E_{11}, E_{12})/C\kappa$ ), and the signal at the output of the photomatrix obtained by laser sensing.

For the construction of optical-galvanic sensors, the methods of selecting galvanic pairs for each type of reservoir pollution by coal combustion products in the boilers of the power unit of the TPP (Burshtyn) were analyzed.

Table. 1.

**Potential Difference Analysis for Selecting an Optical-Galvanic Pair to Assess the Concentration of Harmful Emissions (base metals)**

		Li <sup>+</sup>	Rb <sup>+</sup>	Cs <sup>+</sup>	K <sup>+</sup>	Ba <sup>2+</sup>	Ca <sup>2+</sup>	Na <sup>+</sup>	Mg <sup>2+</sup>	Al <sup>3+</sup>
		-3.05	-2.93	-2.92	-2.92	-2.91	-2.87	-2.71	-2.37	-1.66
Li <sup>+</sup>	-3.05	0	0.12	0.13	0.13	0.14	0.18	0.34	0.68	1.39
Rb <sup>+</sup>	-2.93	0.12	0	0.01	0.01	0.02	0.06	0.22	0.56	1.27
Cs <sup>+</sup>	-2.92	0.13	0.01	0	0	0.01	0.05	0.21	0.55	1.26
K <sup>+</sup>	-2.92	0.13	0.01	0	0	0.01	0.05	0.21	0.55	1.26
Ba <sup>2+</sup>	-2.91	0.14	0.02	0.01	0.01	0	0.04	0.2	0.54	1.25
Ca <sup>2+</sup>	-2.87	0.18	0.06	0.05	0.05	0.04	0	0.16	0.50	1.21
Na <sup>+</sup>	-2.71	0.34	0.22	0.21	2.71	0.2	0.16	0	0.34	1.05
Mg <sup>2+</sup>	-2.37	0.68	0.56	0.55	0.55	0.54	0.50	0.34	0	0.71

Table. 2.

**Potential Difference Analysis for Selecting an Optical-Galvanic Pair to Assess the Concentration of Harmful Emissions (amphoteric metals)**

		Li <sup>+</sup>	Rb <sup>+</sup>	Cs <sup>+</sup>	K <sup>+</sup>	Ba <sup>+</sup>	Ca <sup>+</sup>	Na <sup>+</sup>	Mg <sup>2+</sup>	Al <sup>3+</sup>
		-3.05	-2.93	-2.92	-2.92	-2.91	-2.87	-2.71	-2.37	-1.66
Al <sup>3+</sup>	-1.66	1.39	1.27	1.26	1.26	1.25	1.21	1.05	0.71	0
Mn <sup>2+</sup>	-1.18	1.87	1.75	1.74	1.74	1.73	1.69	1.53	1.19	0.48
Zn <sup>2+</sup>	-0.76	2.29	2.17	2.16	2.16	2.15	2.11	1.95	1.61	0.9
Cr <sup>3+</sup>	-0.74	2.31	2.19	2.18	2.18	2.17	2.13	1.97	1.63	0.92
Fe <sup>2+</sup>	-0.44	2.61	2.49	2.48	2.48	2.03	2.43	2.27	1.93	1.22
Cd <sup>2+</sup>	-0.4	2.65	2.53	2.52	2.52	2.51	2.47	2.31	1.97	1.26
Co <sup>2+</sup>	-0.28	2.77	2.65	2.64	2.64	2.63	2.59	2.43	2.09	1.38
Ni <sup>2+</sup>	-0.24	2.81	2.69	2.68	2.68	2.67	2.63	2.47	2.13	1.42
Sn <sup>2+</sup>	-0.14	2.91	2.79	2.78	2.78	2.77	2.73	2.57	2.23	1.52
Pb <sup>2+</sup>	-0.13	2.92	2.8	2.79	2.79	2.78	2.74	2.58	2.24	1.53
2H <sup>+</sup>	0	3.05	2.93	2.92	2.92	2.91	2.87	2.71	2.37	1.69

Table 3.

**Potential Difference Analysis for Selecting an Optical-Galvanic Pair to Assess the Concentration of Harmful Emissions (acidic metals)**

		Li <sup>+</sup>	Rb <sup>+</sup>	Cs <sup>+</sup>	K <sup>+</sup>	Ba <sup>+</sup>	Ca <sup>+</sup>	Na <sup>+</sup>	Mg <sup>2+</sup>	Al <sup>3+</sup>
		-3.05	-2.93	-2.92	-2.92	-2.91	-2.87	-2.71	-2.37	-1.66
Cu <sup>2+</sup>	+0.34	3.39	3.27	3.26	3.26	3.25	3.21	3.05	2.71	2.00
OH <sup>-</sup>	+0.40	3.45	3.33	3.32	3.32	3.31	3.27	3.11	2.77	2.06
Hg <sup>2+</sup>	+0.79	3.84	3.72	3.71	3.71	3.70	3.66	3.50	3.16	2.45
Ag <sup>+</sup>	+0.80	3.85	3.73	3.72	3.72	3.71	3.67	3.51	3.17	2.46
Pt <sup>2+</sup>	+1.20	4.25	4.13	4.12	4.12	4.11	4.07	3.91	3.57	2.86

Table 4.

**Potential Difference Analysis for Selecting an Optical-Galvanic Pair to Assess the Concentration of Harmful Emissions (basic and amphoteric metals)**

		Mn <sup>2+</sup>	Zn <sup>2+</sup>	Cr <sup>3+</sup>	Fe <sup>2+</sup>	Cd <sup>2+</sup>	Co <sup>2+</sup>	Ni <sup>2+</sup>	Sn <sup>2+</sup>	Pb <sup>2+</sup>
		-1.18	-0.76	-0.74	-0.44	0.40	-0.28	-0.24	-0.14	-0.13
Li <sup>+</sup>	-3.05	1.87	2.29	2.31	2.61	2.65	2.77	2.81	2.91	2.92
Rb <sup>+</sup>	-2.93	1.75	2.17	2.19	2.49	2.53	2.65	2.69	2.79	2.80
Cs <sup>+</sup>	-2.92	1.74	2.16	2.18	2.48	2.52	2.64	2.68	2.78	2.79
K <sup>+</sup>	-2.92	1.74	2.16	2.18	2.48	2.52	2.64	2.68	2.78	2.79
Ba <sup>2+</sup>	-2.91	1.73	2.15	2.17	2.47	2.51	2.63	2.67	2.77	2.78
Ca <sup>2+</sup>	-2.87	1.69	2.11	2.13	2.43	2.47	2.59	2.63	2.73	2.74
Na <sup>+</sup>	-2.71	1.53	1.95	1.97	2.27	2.31	2.43	2.47	2.57	2.58
Mg <sup>2+</sup>	-2.37	1.19	1.61	1.63	1.93	1.97	2.09	2.13	2.23	2.24
Al <sup>3+</sup>	-1.66	0.48	0.090	0.92	1.22	1.26	1.38	1.42	1.52	1.53
		Mn <sup>2+</sup>	Zn <sup>2+</sup>	Cr <sup>3+</sup>	Fe <sup>2+</sup>	Cd <sup>2+</sup>	Co <sup>2+</sup>	Ni <sup>2+</sup>	Sn <sup>2+</sup>	Pb <sup>2+</sup>
		-1.18	-0.76	-0.74	-0.44	-0.40	-0.28	-0.24	-0.14	-0.13
Mn <sup>2+</sup>	-1.18	0	0.42	0.44	0.74	0.78	0.90	0.94	1.04	1.05
Zn <sup>2+</sup>	-0.76	0.42	0	0.02	0.32	0.36	0.48	0.52	0.62	0.63
Cr <sup>3+</sup>	-0.74	0.44	0.02	0	0.30	0.34	0.46	0.50	0.60	0.61
Fe <sup>2+</sup>	-0.44	0.74	0.32	0.30	0	0.01	0.16	0.20	0.30	0.31
Cd <sup>2+</sup>	-0.4	0.78	0.36	0.34	0.04	0	0.12	0.16	0.26	0.27
Co <sup>2+</sup>	-0.28	0.90	0.48	0.46	0.16	0.12	0	0.04	0.14	0.15
Ni <sup>2+</sup>	-0.24	0.94	0.52	0.50	0.20	0.16	0.04	0	0.10	0.11
Sn <sup>2+</sup>	-0.14	1.04	0.62	0.60	0.30	0.26	0.14	0.10	0	0.01
Pb <sup>2+</sup>	-0.13	1.05	0.63	0.61	0.31	0.27	0.15	0.11	0.01	0
2H <sup>+</sup>	0	1.18	0.76	0.74	0.44	0.40	0.28	0.24	0.14	0.13

Table 5.

**Potential Difference Analysis for Selecting an Optical-Galvanic Pair to Assess the Concentration of Harmful Emissions (acid and amphoteric metals)**

		Mn <sup>2+</sup>	Zn <sup>2+</sup>	Cr <sup>3+</sup>	Fe <sup>2+</sup>	Cd <sup>2+</sup>	Co <sup>2+</sup>	Ni <sup>2+</sup>	Sn <sup>2+</sup>	Pb <sup>2+</sup>
		-1.18	-0.76	-0.74	-0.44	-0.40	-0.28	-0.24	-0.14	-0.13
Cu <sup>2+</sup>	+0.34	1.52	1.10	1.08	0.78	0.74	0.62	0.58	0.48	0.47
OH <sup>-</sup>	+0.40	1.58	1.16	1.14	0.84	0.80	0.68	0.64	0.54	0.53
Hg <sup>2+</sup>	+0.79	1.97	1.55	1.53	1.23	1.19	1.07	1.03	0.93	0.92
Ag <sup>+</sup>	+0.80	1.98	1.56	1.54	1.24	1.20	1.08	1.04	0.94	0.93
Pt <sup>2+</sup>	+1.20	2.38	1.96	1.94	1.64	1.60	1.48	1.44	1.34	1.33

		2H <sup>+</sup>	Cu <sup>2+</sup>	OH/O <sub>2</sub>	Hg <sup>2+</sup>	Ag <sup>+</sup>	Pt <sup>2+</sup>
		0	+0.34	+0.40	+0.79	+0.80	+1.20
Li <sup>+</sup>	-3.05	3.05	3.39	3.45	3.84	3.85	4.25
Rb <sup>+</sup>	-2.93	2.93	3.27	3.33	3.72	3.73	4.13
Cs <sup>+</sup>	-2.92	2.92	3.26	3.32	3.71	3.72	4.12
K <sup>+</sup>	-2.92	2.92	3.26	3.32	3.71	3.72	4.12
Ba <sup>2+</sup>	-2.91	2.91	3.25	3.31	3.70	3.71	4.11
Ca <sup>2+</sup>	-2.87	2.87	3.21	3.27	3.66	3.67	4.07
Na <sup>+</sup>	-2.71	2.71	3.05	3.11	3.50	3.51	3.91
Mg <sup>2+</sup>	-2.37	2.37	2.71	2.77	3.16	3.17	3.57
Al <sup>3+</sup>	-1.66	1.66	2.00	2.06	2.45	2.46	2.86

Table 6.

**Potential Difference Analysis for Selecting an Optical-Galvanic Pair to Assess the Concentration of Harmful Emissions (acid and amphoteric metals)**

		2H <sup>+</sup>	Cu <sup>2+</sup>	OH/O <sub>2</sub>	Hg <sup>2+</sup>	Ag <sup>+</sup>	Pt <sup>2+</sup>
		0	+0.34	+0.40	+0.79	+0.80	+1.20
Mn <sup>2+</sup>	-1.18	1.18	1.52	1.58	1.97	1.98	2.38
Zn <sup>2+</sup>	-0.76	0.76	1.10	1.16	1.55	1.56	1.96
Cr <sup>3+</sup>	-0.74	0.74	1.08	1.18	1.53	1.54	1.94
Fe <sup>2+</sup>	-0.44	0.44	0.78	0.84	1.23	1.24	1.64
Cd <sup>2+</sup>	-0.4	0.40	0.74	0.80	1.19	1.20	1.60
Co <sup>2+</sup>	-0.28	0.28	0.62	0.68	1.07	1.08	1.48
Ni <sup>2+</sup>	-0.24	0.24	0.58	0.64	1.03	1.04	1.44
Sn <sup>2+</sup>	-0.14	0.14	0.48	0.54	0.93	0.94	1.34
Pb <sup>2+</sup>	-0.13	0.13	0.47	0.53	0.92	0.93	1.33
2H <sup>+</sup>	0	0	0.34	0.40	0.79	0.80	1.20

Lasers with a power of 50 mW and two types of electrode pairs were used to activate the galvanic couple. The following type of laser was used for the measurement "RADIATION "DANGER"" Power 50mW.

Table 7.

**Loss of laser power in the cuvette when sounding the medium**

Reak N	P laser mW	P laser without water	P laser with running water	Rx kΩ (Zn/Zn) H <sub>2</sub> O	Ux μV (Zn/Cu) H <sub>2</sub> O	Rx kΩ with laser	Ux μV with laser
1	50	37	40	679-753	0,5	1015	0,6
2	50	40	40	679-830	0,4	1030	0,8
3	50	38	40	679-834	0,4	1005	0,9
4	50	37	43	679-824	0,5	995	0,6
5	50	39	40	650-768	0,6	932	0,7
6	50	40	44	670- 820	0,6	968	0,6
7	50	40	44	670-908	0,5	1060	0,5
8	50	40	42	739-868	0,5	1040	0,6

Integration of information and laser technologies for assessing the concentration of harmful gas and dust emissions into the eco-social system by man-made infrastructure. The level of the total risk of environmental impact is determined in accordance with the procedure for a comprehensive assessment of the probability of exceeding the concentration, namely

$$\sum \alpha_{risk} \leq \bigotimes_{n=1,m}^{dn} \left( \text{Prob}(\alpha_{risk}^i(C_k, Re gi) > \alpha_{ri}^d) \right) \quad (6)$$

where:  $\alpha_{ri}^d(R_{gi})$  - is the level of permissible maximum risk for each component according to DSTU;

$\sum \alpha_{risk}$  - total risk of exceeding reagent concentrations;

$A_n(\otimes / i = 1, n)$  - operator for assessing the total multi-risk.

In order to assess the spatial distribution of environmental pollution (villages, cities, regions) and risk assessment, it is necessary to perform a large amount of calculations on the results of data collection and sampling using information technology as the basis for developing hybrid environmental monitoring systems.

### Research results discussion

The obtained results confirm the effectiveness of the integrated use of information and laser technologies for assessing the concentration levels of harmful emissions in technogenic ecosystems. The proposed approach, based on the combination of laser remote sensing methods and opto-galvanic sensors, enables continuous real-time monitoring of the state parameters of air, water, and liquid environments, in contrast to traditional laboratory methods, which are time-consuming and inertial.

The analysis of electrode potential differences demonstrated the feasibility of a rational selection of galvanic pairs for evaluating the concentration of harmful components of various chemical natures, including basic, amphoteric, and acidic metals. The results presented in the tables indicate a high sensitivity of opto-galvanic sensors to changes in impurity concentrations in solutions, confirming the appropriateness of their application for monitoring pollution in reservoirs and industrial wastewater.

Experimental studies using a semiconductor laser with a power of 50 mW showed that laser radiation significantly affects the intensity of galvanic processes in the measuring cell by activating electrochemical interactions between the electrodes and the medium. The recorded laser power losses in the cuvette and the variations in voltage at the photodetector output confirm the feasibility of constructing calibration characteristics for the quantitative assessment of impurity concentrations.

The integration of measurement data within the framework of an environmental monitoring information model enables a comprehensive assessment of cumulative environmental risk, taking into account the multifactorial nature of pollution and the spatial distribution of harmful emissions. This is particularly important under conditions of technogenic accidents and military actions, where rapid decision-making is required to minimize adverse impacts on the environment and public health.

### Conclusion

This paper proposes and substantiates a comprehensive environmental monitoring approach based on the integration of information technologies, laser remote sensing, and opto-galvanic methods for controlling the concentration of harmful emissions in air and liquid environments.

An information and structural model of the measurement system has been developed, providing continuous real-time monitoring of pollutant concentrations and enhancing the efficiency of environmental risk assessment.

An analysis of electrode potential differences made it possible to identify optimal galvanic pairs for evaluating the concentrations of basic, amphoteric, and acidic metals, which are characteristic components of technogenic emissions.

The effectiveness of laser radiation for activating galvanic processes in the measurement cell and increasing sensor sensitivity to changes in impurity concentrations has been experimentally confirmed.

The proposed method for integrated assessment of cumulative environmental risk allows for consideration of the multicomponent composition of pollution as well as the spatio-temporal dynamics of harmful emission propagation in technogenic ecosystems.

The obtained results can be applied in the development of hybrid environmental monitoring systems for printing, industrial, energy, and municipal facilities, as well as in decision support systems aimed at ensuring environmental safety under conditions of increased technogenic and military threats.

### ADDITIONAL INFORMATION

#### AUTHOR CONTRIBUTIONS

Conceptualization L.S.; methodology L.S.; validation N.L.; formal analysis, O.F.; investigation, N.L.; writing - original draft preparation, L.S., N.L.; writing - review and editing, O.F.; visualization, N.L.; project administration, O.F.

#### DECLARATION ON THE USE OF GENERATIVE ARTIFICIAL INTELLIGENCE TOOLS

In preparing this work, the author used Grammarly for: grammar and spelling checks. After using this tool/service, author reviewed and edited the content and take full responsibility for the content of this publication.

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## ІНТЕГРАЦІЯ ЛАЗЕРНИХ ТА ОПТИКО-ГАЛЬВАНІЧНИХ МЕТОДІВ У СИСТЕМАХ ЕКОМОНІТОРИНГУ ТЕХНОГЕННИХ ОБ'ЄКТІВ

*Сучасний рівень розвитку електроенергетичної, хімічної, машинобудівної та поліграфічної галузей характеризується залученням значної кількості ресурсних компонентів, зокрема вугілля, нафти, природного газу, лакофарбових матеріалів і полімерів, які відзначаються підвищеною екологічною агресивністю. Високоінтенсивні режими функціонування виробництв, зумовлені вимогами ринку, спричиняють суттєве зростання споживання ресурсів у енергоємних технологічних процесах. Це, у свою чергу, призводить до підвищення концентрації пилу, а також шкідливих газоподібних і рідинних викидів в атмосферне та водне середовище, що обумовлює загальне погіршення стану довкілля. При цьому оперативна оцінка екологічного стану у реальному часі часто ускладнена через обмежені можливості збору та опрацювання даних із використанням традиційних методів вимірювання.*

*Існує значна кількість інформаційно – вимірювальних систем і лабораторних методів і приладів для вимірювання вмісту (концентрації) шкідливих викидів в атмосферу, ґрунти і води екосистеми, але всі вони ґрунтуються на відборі екопроб і їх обробці в лабораторних умовах, що вимагає певного часу. В технологічних системах використовується контроль – вимірювальні пристрої і сенсори (давачі), але вони не забезпечують вимірювання критичних параметрів процесу виробництва в ході якого утворюються потоки забруднюючих речовин.*

*Прикладом є викиди продуктів згорання в котлах енергоблоків теплових електростанцій та комунальних систем, будівництві, транспорті та авіації, підприємствах нафтопереробної і газової промисловості, хімічних заводів, як державної так і приватної власності.*

*У цьому контексті проблема екомоніторингу (створення систем, структур, сенсорів) є актуальною з технічного боку і важливою в соціальному значенні.*

*Відповідно розробка інформаційних технологій відбору даних для екомоніторингу екологічного середовища (атмосфери, вод, ґрунтів) на підставі оптико – гальванічних методів контролю забруднення навколишнього середовища та методів лазерного дистанційного вимірювання концентрації шкідливих викидів газів, продуктів згорання, пилу є актуальною, так як вони забезпечують неперервний контроль їх концентрації.*

*Ключові слова: екосистема, атмосфера, пил, контроль, лазери, екологічна безпека, датчики.*