INFORMATION-MEASURING SYSTEM FOR MICROCLIMATE CONTROL IN THE EXHIBITION MODULES OF THE KYIV ZOO

Valerii Zdorenko, Dr.Sc., Prof., Maksym Basaliuk, PhD Student,
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine
Oksana Moroz-Parkhomenko
Київський зоологічний парк загальнодержавного значення
e-mail: m.basaliuk@gmail.com
e-mail: alzd123@meta.ua
e-mail: oksmoroz.kiev.zoo@gmail.com

https://doi.org/10.23939/istcmtm2025.03.

Abstract. This paper is dedicated to the development of a unified system for monitoring microclimate parameters in the terrariums of the Kyiv Zoo. In cooperation with zoo representatives, existing methods and devices for artificially creating a microclimate in exhibition modules were reviewed and analyzed. The issues of this process were examined, and the main parameters for animal housing conditions were determined, such as air or water temperature, humidity, illumination, and the level of ultraviolet radiation. Six exhibition modules were selected for experimental studies. Based on the research and familiarization, a structural diagram of the information-measuring system for microclimate control for the first module was developed, describing the system's operation principle and functionality. Appropriate sensors that meet the set tasks were selected, as well as the necessary actuators for the exhibition module. The advantages and disadvantages of the system were presented in the conclusion.

Key words: Information-measuring system, microclimate, temperature, humidity, ultraviolet radiation level, terrarium, experimental exhibition module.

1. Introduction

The founder and owner of the Kyiv Zoo is the territorial community of the city of Kyiv, represented by the Kyiv City Council. The zoo was established on March 21, 1909, by the Kyiv Society of Nature Lovers to exhibit rare, exotic, and local animals, preserve their gene pool, study wildlife, develop scientific foundations for breeding animals in artificially created conditions, and organize environmental and educational activities. According to the resolution of the Council of Ministers of the Ukrainian SSR dated July 22, 1983, No. 311 "On the classification and network of territories and objects of the nature reserve fund of the Ukrainian SSR," the zoo was included among the nature reserve objects of national importance [1].

The zoo's territory is divided into the following zones: the exhibition zone – intended for the stationary keeping of animals and their use for cultural and educational purposes; the scientific zone – intended for scientific research, with access allowed as per zoo administration regulations; the recreational zone – designed for visitors' rest and service; and the economic zone – designated for housing auxiliary facilities [2].

The main purpose of the zoo is to preserve the biodiversity of wild animals, including those highly sensitive to environmental conditions such as reptiles and amphibians. For these animals, individual terrariums must be created that maintain a specific microclimate reflecting their natural habitats [4]. Therefore, improving the methods of controlling temperature, humidity, and ultraviolet (UV) radiation in terrariums is an urgent necessity. The development of information-measuring systems aimed at ensuring optimal environmental conditions (temperature, humidity, and UV radiation) for keeping animals in captivity is essential for comprehensive control over devices and systems, ultimately enhancing animals' physical and mental well-being [3].

2. Drawbacks

An important aspect of creating a microclimate in terrariums is the continuous maintenance of its parameters at optimal levels, which usually include temperature, humidity, illumination, and ultraviolet radiation level. For the effective functioning and healthy life of animals, it is necessary to constantly monitor the proper operation of devices in the terrarium that ensure the creation of a suitable microclimate, as well as regulate them depending on time changes and the condition of the environment both inside and outside.

3. Goal

The objective of this paper is to develop an automated information-measuring system that performs monitoring and control of microclimate parameters in the terrarium at the appropriate level and with the required accuracy, without constant human intervention.

4. Overview of the Exhibition Module and Problem Statement

During the analysis of existing devices that monitor environmental parameters in the exhibition modules of the «Island of Animals» pavilion at the Kyiv Zoo, six experimental exhibition modules (EEMs) were identified (Fig. 1).

For the development of the information-measuring system, the first exhibition module (EEM 1) was selected, which houses a water dragon and ctenopoma fish together (Fig. 2). The water dragon leads a semi-arboreal and semi-aquatic lifestyle, is active during the day, swims well, and in case of danger jumps or simply falls from branches into the water. If necessary, it can dive and remain underwater for up to 20 minutes. It feeds on insects and small vertebrates. In captivity, it also eats fruit and vegetable mixtures [5]. Ctenopoma fish live in fresh, slow-flowing water with moderate filtration.

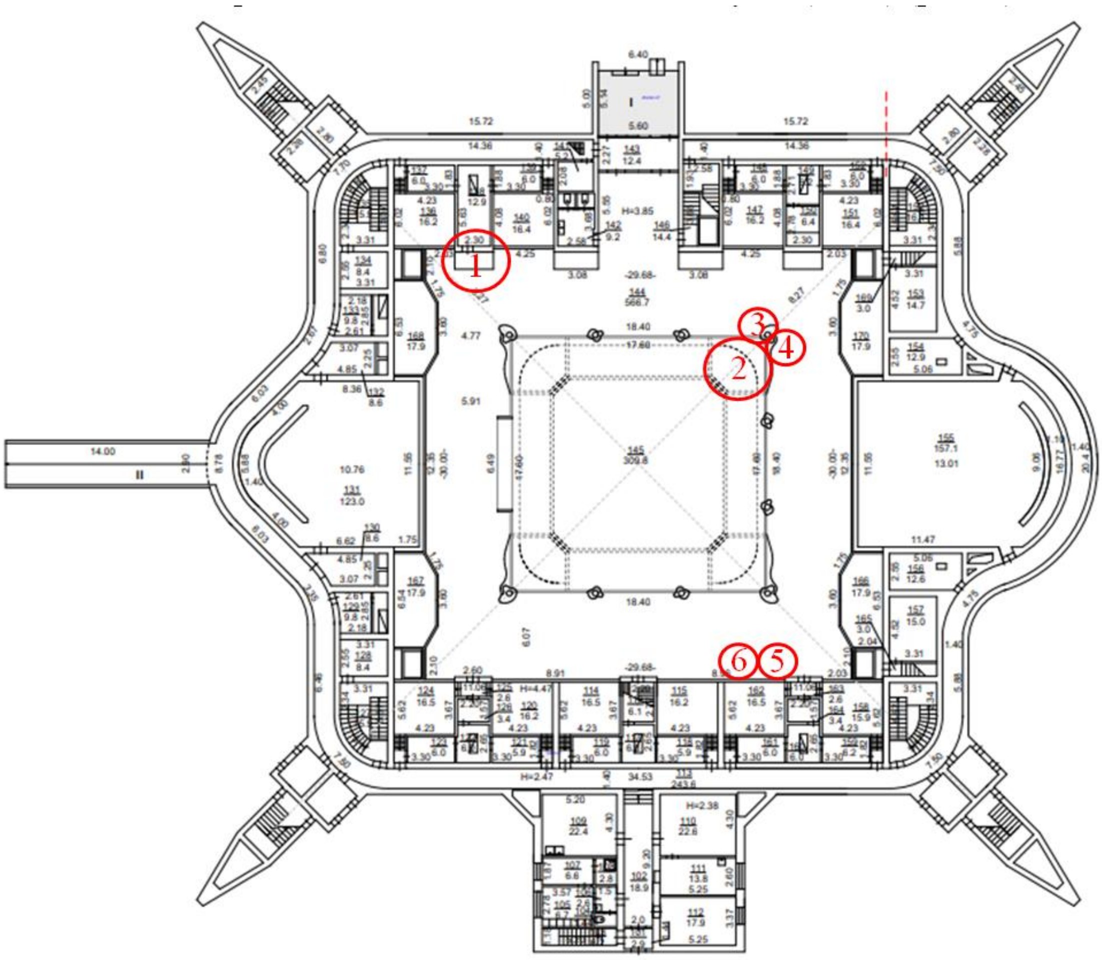

Fig. 1. Location of EEMs (№№1 – 6) in the «Island of Animals» pavilion: 1 - EEM 1 Water dragon and ctenopoma fish; 2 - EEM 2 Nile fruit bat; 3 - EEM 3 Emperor scorpion; 4 - EEM 4 Blue spider; 5 - EEM 5 Yemen chameleon; 6 - EEM 6 Boivin's gecko

Fig. 2. General view of the first experimental exhibition module (EEM 1) «Water dragon and ctenopoma fish»

For the first experimental module, the optimal ranges of main environmental parameters for the joint exhibition of the water dragon and ctenopoma fish (EEM 1) were determined:

- Temperature: Water dragon – 28–30 °C (day) / 22–24 °C (night); Ctenopoma fish – 24–28 °C;
- Air humidity: Water dragon – 80–90%;
- Light radiation: Optimal for live plants – 5000–6500 K, 400–600 nm; optimal for animals – 4000–6500 K, 280–320 nm;
- Optimal air exchange: For a terrarium with reptiles and air volume of 5.15 m^3, the optimal air exchange rate is 15.45 m^3/hour.

5. Mathematical Model

The microclimate control and regulation object in the terrarium is characterized by spatially distributed parameters, since air humidity φ=φ(t, x, y, z) and temperature T=T(t, x, y, z) of the internal air environment depend not only on time t but also on the spatial coordinates x, y, z of the measurement point.

A mathematical model describing the dynamics of air temperature changes in the terrarium under control actions has been developed. This model is presented in the form of a differential equation and a transfer function. The model considers a terrarium heated by two heaters located at its ends (Fig. 3).

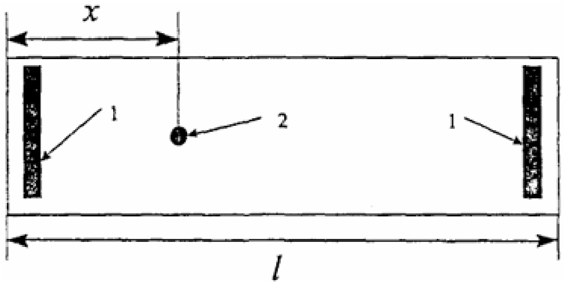

Fig. 3. Terrarium heating system.
1 – heater; 2 – temperature sensor.

The air temperature in the terrarium T(x, t) satisfies the heat conduction equation:

$$\frac{\partial T(x,t)}{\partial t} = a^2 \frac{\partial^2 T(x,t)}{\partial x^2} + f_T(x,t), \qquad (1)$$

where a is the air thermal diffusivity coefficient considering convection, and $f_T(x,t)$ is the density of heat sources at the point with coordinate x at time t.

Equation (1) is solved under the following boundary conditions:

$$T(0,t) = T(l,t) = q(t), \qquad (2)$$

where q(t) is the control action, and l is the length of the terrarium.

Taking into account equations (1) and (2), the following analytical expression was derived for the transfer function of the temperature control channel T(x, t):

$$W_{gt}(\chi,p) = \frac{e^{\chi\sqrt{p}} - e^{-\chi\sqrt{p}} + e^{(1-\chi)\sqrt{p}} - e^{-(1-\chi)\sqrt{p}}}{e^{\sqrt{p}} - e^{-\sqrt{p}}}, \qquad (3)$$

where p is the dimensionless complex variable and $\chi = x / l$.

Based on the resulting model (3), a method was developed for determining the optimal placement and minimum number of air temperature sensors in the terrarium.

The described method is based on the following reasoning. Let $T_{зд}$ be the temperature setpoint in the terrarium. Then the control task for the temperature field T(t, x, y, z) can be formulated as the following requirement:

$$\max |T_{зд} - T(t, x, y, z)| = \min, \qquad (4)$$

where x, y, z are the spatial coordinates of a point in the terrarium where condition (4) is evaluated; t is time.

In this study, we consider the simplest single-loop control system with one temperature controller. The tuning parameters of this controller are determined so that the following condition is met:

$$|T_{зд} - T(t, x_\mu, y_\mu, z_\mu)| = \min, \qquad (5)$$

where the coordinates x_μ, y_μ, z_μ are selected such that:

$$|T_{зд} - T(t, x_\mu, y_\mu, z_\mu)| = \max |T_{зд} - T(t, x, y, z)|. \qquad (6)$$

Thus, based on requirement (6), the critical point with coordinates x_μ, y_μ, z_μ , is identified, at which the deviation of temperature T(t, x, y, z) from the setpoint $T_{зд}$ is maximal. In turn, satisfying requirement (5) allows this deviation to be minimized. As a result, the overall requirement (4) is fulfilled.

A temperature sensor should be placed at the critical point x_μ, y_μ, z_μ as this ensures the desired control quality of the temperature throughout the entire terrarium volume.

Studies have shown that the temperature control channel in the terrarium, q(t) → T(t, x_μ, y_μ, z_μ) is the most inertial compared to other control channels. Therefore, condition (6) applies to it. Consequently, tuning the temperature controller to satisfy condition (5) ensures better temperature control quality at all other points in the terrarium compared to the critical point.

The developed method allows analyzing the dependence of the dynamic characteristics of the air temperature control channel in the terrarium on the placement of temperature sensors. The described method enables not only correct placement of air temperature sensors but also minimizing their quantity without compromising temperature control quality. Using the proposed method, it was determined that a single temperature sensor is sufficient for effective air temperature monitoring and control in the terrarium under study. Information from temperature sensors placed elsewhere would be redundant.

It was also established that the dynamic characteristics of the air humidity control channel in the terrarium are similar to those of the temperature control channel. Therefore, in this work, the same analysis method was applied to determine the optimal placement and minimum number of humidity sensors. Based on this method, it was found that a single humidity sensor is sufficient for high-quality humidity control in the studied terrarium, with its location chosen to ensure the maximum inertial response of the humidity control channel.

6. Development of the System

Reptiles and amphibians are cold-blooded animals, so for the normal functioning of their bodies, an environment with temperature gradients is necessary – with separate warm and cool zones. To prevent overheating or hypothermia, it is necessary to constantly measure the temperature in both areas of the terrarium.

Moreover, for the synthesis of vitamin D3, each species of reptile requires ultraviolet radiation of a certain wavelength, provided by a special UV lamp. Over time, the lamp's radiation may decrease, although this is difficult to detect visually, so its intensity and proper functioning must be checked regularly.

Therefore, there is a need to create a system that simultaneously monitors temperature and humidity in different zones of the terrarium, as well as the level of UV radiation from the lamp [6–9].

Based on these environmental parameter characteristics, a diagram was developed for the automated information-measuring system for controlling devices in EEM 1 «Water dragon and ctenopoma fish» (Fig. 4).

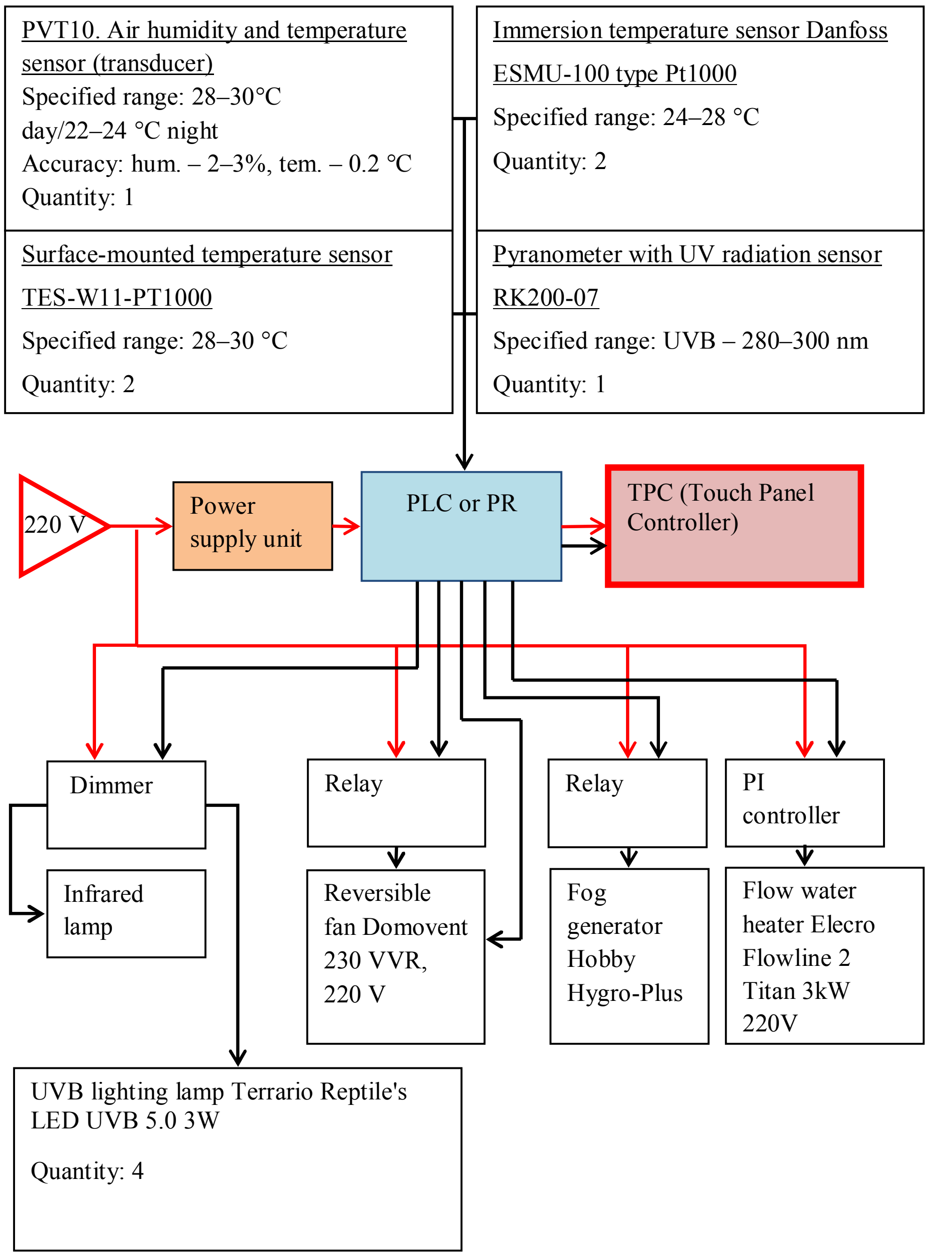

Fig. 4. Control diagram for devices in EEM1 «Water dragon and ctenopoma fish»

The PVT10 sensor is used to monitor air temperature and humidity, converting the input parameters into two standardized output signals: 4–20 mA current or 0–10 V voltage. For surface temperature monitoring, the surface-mounted TES-W11-PT1000 sensor is used. Water temperature is measured by Danfoss ESMU-100 immersion sensors. Additionally, the system includes UV wavelength monitoring via the RK200-07 sensor with a standardized 4–20 mA output signal.

The controller cabinet is the most important element of the control system. It houses a programmable logic controller (PLC), or optionally a programmable relay (PR). The controller manages system operation and outputs data to external information consumers.

The touch panel controller (TPC) allows multiple controllers to be connected to it, displaying the microclimate status of other terrariums and enabling system expansion to other modules.

The control system operates as follows: signals from the sensors reflecting the monitored parameter values are sent to the controller's input modules, where they are converted and scaled. These converted signals are read by the controller for further logical analysis. Based on the analysis, the controller sends information signals to output modules, which in turn determine the settings for the actuating devices [10, 11].

This system performs the following functions: Monitoring and control of actuating devices in the terrarium; Collection, processing, and transmission of accurate operational data to external systems; Archiving of technological process data and presenting it in convenient formats for analysis (text, graphs, histograms, etc.).

As a result of the analysis, the advantages of this system include extensive capabilities for collecting, analyzing, processing, operational display, and archiving microclimate parameter data, as well as automated control of actuators inside the terrarium without constant human involvement.

The disadvantages of the system are its dependence on a large volume of input data for reliable operation, and limited adaptability under unpredictable changes in control object parameters.

7. Conclusions

In this work, an information-measuring system was developed for monitoring microclimate parameters in the exhibition module housing the water dragon and ctenopoma fish at the Kyiv Zoo. The system includes temperature, humidity, and ultraviolet radiation sensors, as well as actuators that ensure optimal conditions are maintained. A mathematical model of the temperature field dynamics in the terrarium was proposed, which made it possible to determine the critical points for placing sensors and to optimize their quantity. The advantages of the developed system include high measurement accuracy, automation of the control process, the ability to archive data, and scalability to other modules. The disadvantages are its dependence on the quality of input data and limited adaptability in the event of abrupt changes in external conditions. Overall, the system can significantly improve the conditions for keeping animals and reduce the workload on zoo staff.

Conflict of Interest

The authors declare no financial or other potential conflicts of interest regarding this work.

References

[1] Kovalynskyi, V. V. The History of Kyiv Zoo, 2009.
[2] Shkvyrya, M., Trantin, K. (Eds.). Kyiv Zoo: Developing Scientific Potential, 2021.
[3] Regulation on the Kyiv Zoological Park of National Importance, Order of the Ministry of Ecology No. 119, April 13, 2018.
[4] C. Jayasundara et al., "IoT Based Smart Monitoring System for Terrarium," in Proc. Int. Conf. on Smart Computing and Systems Engineering, 2022. [Online]. Available: https://doi.org/10.1109/ICSCS.2022.00034.
[5] McKeown, S. The General Care and Maintenance of Green Water Dragons, Advanced Vivarium Systems, 1997.
[6] Association of Zoological Institutions of Ukraine (AZU), "The Terrarium as an Integral Component of the Modern Zoo," AZU Collection, 2023. [Online]. Available: https://azu.org.ua/works/zbirnik-terarium-yak-nevid%D1%94mna-skladova-suchasnogo-zooparku.
[7] Schmidt, M., et al. "Design and Implementation of Smart Terrarium Systems," Sensors, vol. 21, no. 11, 2021. Available: https://www.mdpi.com/1424-8220/21/11/3871.
[8] M. Lee and H. Kim, "Ultraviolet Light Monitoring for Reptile Enclosures Using Embedded Systems," Applied Sciences, vol. 11, no. 15, 2021. [Online]. Available: https://doi.org/10.3390/app11156988.
[9] Sharma, R., Kumar, A. "IoT Based Environment Monitoring in Reptile Habitats," International Journal of Advanced Computer Science, vol. 10, no. 5, pp. 92–97, 2020.
[10] O. J. Shtifzon, P. V. Novikov, and V. P. Bun', "Theory of Automatic Control: Textbook," KPI, 2020. [Online]. Available: https://elib.lntu.edu.ua/sites/default/files/elib_upload/2020_theory_auto_control.pdf.
[11] A. A. Marchenko and V. S. Huliy, "Theory of Automatic Control. Part 1: Computer Practicum," KPI, 2022. [Online]. Available: https://ela.kpi.ua/handle/123456789/52914.