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GEOLOGY

Problems of Artificial Intelligence in Ecological Forecasting

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Two multidisciplinary problems exist in the field of ecological forecasting: (i) measurements in soil, air, and water; (ii) interpretation of these measurements for forecasting or making administrative decisions about industrial activity. The main issue in the solution to the first problem is realization of the object of research (scope of measured properties, establishment of scales, and accuracy of measurements) at present and development of theoretical ecology in the future. The main difficulty in the solution to the second problem is the choice and use of mathematical methods applicable to the problems and quality of measurements [2].

Scales of measurements in ecological monitoring are frequently unknown, and data errors are sufficiently large. Moreover, expert determinations are very frequently present. Therefore, it is difficult to substantiate the classical models of interpretation (methods of linear algebra, differential and integral calculus). Nonclassical models require sufficiently greater volumes of data than those available in the modern experimental ecology. It seems that models of artificial intelligence (Lotfi Zadeh's theory of fuzzy sets, Shannon's information theory, finite classifications, cluster analysis, and recognition approach) are adequate for the problems and quality of measurements in ecology. Below, we shall analyze problems of the prognosis of ecological stress in a region with a known source of pollution and estimate the quality of the consumption resources within the concept of image recognition [3].

We shall interpret the ecological norm not as quantitative restriction of the maximum permissible concentration (MPC), maximum permissible emission (MPE), maximum permissible level (MPL), and maximum permissible norm (MPN), but as the equilibrium state of the triad (society, production, and nature), which should be controlled not by means of the above-mentioned norms (technical–economical control) but by means of monitoring people's health (medical control) and damage to the nature (ecological–economical control).

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Let us consider the basic problems of rational management of nature using the methods of artificial intelligence (AI) [1, 2].

THE PROBLEM OF FORECASTING ECOLOGICAL STRESS IN A NATURE MANAGEMENT REGION

Let us assume that the specified ecologically unfavorable region includes an industrial plant that pollutes nature and its influence beyond the region may be neglected. Let us plot a grid of beams from the pollution source at angles γ_j, $j = 1, 2, \ldots, p$, along which measurements of the state of air f_i ($i = 1, 2, \ldots, n_1$), soil f_i ($i = 1, 2, \ldots, n_2$), and water f_i ($i = 1, 2, \ldots, n_3$) were carried out at time moments t_l with intervals Δr.

Let us consider vector F_M of the state of nature at point (γ_j, r_k) $F_M(\gamma_j, r_k, t_l) = \{f_i(\gamma_j, r_k, t_l)\}$, $i = 1, 2, \ldots, M$, $M = n_1 + n_2 + n_3$. Suppose that we know the variation limits of values f_i, $f_i^* \le f_i(\gamma_j, r_k, t_l) f_i^{**}$ and experts have distinguished ecologically poor $f_i' \ge f_i^*$ and good $f_i'' \le f_i^{**}$ values of properties $f_i(\gamma_j, r_k, t_l)$.

Let us introduce an index of stress at point (γ_j, r_k) at time moment t_l for property f_i based on the introduced [1] pair similarity measures (stage 1)

$$\sigma(\gamma_j, r_k, t_l) = \frac{\lambda\lfloor f_i(\gamma_j, r_k, t_l), f_i'\rfloor}{\lambda[f_i(\gamma_j, r_k, t_l), f_n'] + \lambda[f_i(\gamma_j, r_k, t_l), f_i'']}.$$

Integrated index of ecological stress at point (γ_j, r_k) and time moment t_l based on the set of properties $F_M = f_i$, $i = 1, 2, \ldots, M$ (stage 3) can be written as

$$\sigma_{F_M}(\gamma_j, r_k, t_l) = \sum_{i=1}^{M} \alpha_i \sigma_{f_i}(\gamma_j, r_k, t_l),$$

$$\sum_{i=1}^{M} \alpha_i = 1.$$

We shall consider that point (γ_j, r_k) at time moment t_l is ecologically normal if $\sigma_{F_{ni}}(\gamma_j, r_k, t_l) < \sigma_0$, $i = 1, 2, 3$. We determine the value of σ_0 according to stage 4. In the opposite case, this point at time moment t_l will be considered ecologically anomalous except for the case $\sigma_{F_{ni}}(\gamma_j, r_k, t_l) \approx 0.5$, $i = 1, 2, 3$, which we shall interpret as waiver of forecast.

Joining the neighboring points on the beams with segments of straight lines, we shall get a flat figure with area $S(t)$ at time moment t. Let us assume function $\sigma(R, t) = \frac{S(t)}{S_R}$, where S_R is the area of the region, as the index of ecological stress of the region.

PROBLEM OF ESTIMATION OF THE QUALITY OF CONSUMPTION RESOURCES

In this paper, "consumption resource" means drinking water, air, food, and any consumer goods. The authors of [1] formulate the problem for constructing a direct criterion of potable water quality. We shall try to summarize this experience and construct an indirect criterion for the quality of any consumption resource.

Organization of ecological resources of consumption is one of the important stages of the analysis of this problem: A_0^+ is the best quality and A_0^- is the worst quality.

We assume that, based on different direct properties φ, $i = 1, 2, \ldots, m$, individual experts without personal interests have specified collections of A_0 samples of a specific consumption resource A, $A_0 \subset A$, $A_0 = (\alpha_{ij})$, $i = 1, 2, \ldots, m$, $j = 1, \ldots, N$, where i is the number of direct property φ_i used for determining the resource quality by an individual expert and j is the number of the sample. Then, the direct description of sample a_j is written as $a_j = (\varphi_{ij})$, where i is the number of the sample property available for unique and expensive measurements.

Indirect description of the sample is written as $a_j = (f_{ij})$, $i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, N_0$; and i is the number of the sample property available for unique and expensive measurements.

Further, let us formulate the description matrices for samples of the best quality identified by the experts on the basis of specific properties: $a_j^+ = (\varphi_{ij})$, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, N_0^+$. For samples of the worst quality, $a_j^- = (\varphi_{ij})$, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, N_0^-$.

Among the a_j^+ values, we distinguish the values of $\varphi_i^{**} = \max_j \varphi_{ij}$ and the most typical $\overline{\varphi_+}$ values for a_j^-. Similarly, among the samples of the worst quality a_j^-, we distinguish the values of $\varphi_i^* = \min_j \varphi_{ij}$ and the most typical $\overline{\varphi_-}$ value for a_j^-.

The currently accepted technical–economical criteria can be used as ecological criteria of the efficiency of consumption resources when we speak about the costs of decreasing the MPC to the most characteristic quality. The medical criteria can be used when we mean the serious consequences of consuming $a_j \in A$ by a person.

Let us formulate ecological images of A_0^+ and A_0^- in the following way. According to stage 1, let us introduce a pair similarity measure based on one property $\lambda_\Phi(a_i, a_j)$ and on many properties $\lambda_\Phi(a_i, a_j) = \sum_{i=1}^{n} \alpha_i \lambda_{\Phi_i}(a_i, a_j)$, $\sum_{i=1}^{n} \alpha_i = 1$. Then, the special similarity measure can be written as

$$\lambda(a_i, a_j) = \beta_1 \lambda_\Phi(a_i, a_j) + \beta_2\{1 - 0.5[|\lambda_\Phi(a^*, a_j) - \lambda_\Phi(a^*, a_j)| + |\lambda_\Phi(a^{**}, a_j) - \lambda_\Phi(a^{**}, a_j)|]\},$$

where $\beta_1 + \beta_2 = 1$, $a^* = [\min_j \varphi_{ij}]$, $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, N$.

The ecological degree of sample a_j is controlled by means of quality indices

$$k_1(a_j) = \frac{\lambda_\Phi(a_j, a^{**})}{\lambda_\Phi(a_j, a^*) + \lambda_\Phi(a_j, a^{**})}$$

or

$$k_2(a_j) = \gamma^{**}\lambda_\Phi(a_j, a^{**}) + \gamma^*[1 - \lambda_\Phi(a_j, a^*)],$$

where $\gamma_1 + \gamma_2 = 1$.

The ecological image A_0^+ is considered an organized one if $k(a_j^+) > k_0^+$ for all $a_j^+ \in A_0^+$ and similarly $k(a_j^-) > k_0^-$ for $a_j^- \in A_0^-$.

According to stage 2, we select images A_0^+ and A_0^- in the domain of indirect properties $F = (f_i)$, $i = 1, 2, \ldots, n$. The rational complex $F_k \subset F$ is chosen on the basis of stage 3 with account for the individual and collective descriptiveness [3].

To solve the problem of assessment of the quality of a consumption resource, we shall use the multiple similarity measure $\lambda_F(a_j, A_0^+)$ and forecast decision-making rule (stages 5, 6).

Finally, using the examination data $A_0^э = A_0 \backslash |A_0^+ \cup A_0^-|$, we estimate the efficiency of the solution to the problem. At the start, independent experts without personal interests can be engaged in this work.

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