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INTERAKTYWNY SYSTEM OCENY STANU DRÓG

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Adnotacja. Omówiono problematykę interaktywnego monitorowania i diagnostyki stanu dróg. Metodyka oceny i diagnozowania ich stanu operacyjnego jest składnikiem ogólnego i specjalnego zabezpieczenia informacyjnego, które jest zawarte w infrastrukturze informacyjnej kompleksu transportowego. Poprawa bezpieczeństwa ruchu, prędkości, komfortu i opłacalności przewozu pasażerów i towarów transportem samochodowym, poprawa stanu transportu i eksploatacji autostrad, mostów, zapewnienie systematycznego rozwoju sieci dróg zależy od wystarczającej świadomości użytkowników dróg. Dlatego poprawa wskaźników technicznych, poprawa konkurencyjności autostrad, promowanie zrównoważonego rozwoju społeczno-ekonomicznego i ekologicznego kompleksu transportowego wiąże się ze skutecznym monitorowaniem autostrad, które powinno być głównym źródłem wiarygodnych informacji o stanie szlaków komunikacyjnych na poziomie lokalnym, regionalnym i państwowym.

Słowa kluczowe: monitoring interaktywny, systemy transportowe, szlaki transportowe, podejście synergiczne, opis matematyczny, obserwowany proces dynamiczny.

INTERACTIVE SYSTEM FOR ASSESSING THE CONDITION OF ROADS

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Abstract. The problems of interactive monitoring and diagnostics of the condition of highways are considered. Methods of assessing and diagnosing their operational condition are part of the general and special information support, which is part of the information infrastructure of the transport complex. Improving traffic safety, speed, comfort and efficiency of passenger and freight transport by road, improving the transport and operational condition of roads, bridges, ensuring the systematic development of the road network depends on sufficient awareness of road users. Therefore, improving technical performance, increasing the competitiveness of roads, promoting socio-economic and environmentally sustainable development of the transport complex is associated with effective monitoring of roads, which should be the main source of reliable information about the state of roads at local, regional and national levels.

Key words: interactive monitoring, transport systems, communication routes, synergetic approach, mathematical description, observed dynamic process.

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Анотація. Розглянуто проблематику інтерактивного моніторингу та діагностики стану автомобільних доріг. Методика оцінки і діагностування їхнього експлуатаційного стану є складником загального та спеціального інформаційного забезпечення, яке входить до інформаційної інфраструктури транспортного комплексу. Підвищення безпеки руху, швидкості, комфортності та економічності перевезень пасажирів і вантажів автомобільним транспортом, поліпшення транспортно-експлуатаційного стану автомобільних доріг, мостів, забезпечення планомірного розвитку мережі автомобільних доріг залежить від достатньої інформованості учасників дорожнього руху. Тому покращення технічних показників, підвищення конкурентоспроможності автомобільних доріг, сприяння соціально-економічному та екологічно збалансованому розвитку транспортного комплексу пов'язане з ефективним моніторингом автомобільних доріг, що повинен бути основним джерелом достовірних відомостей про стан шляхів сполучення на місцевому, регіональному та державному рівнях.

Ключові слова: інтерактивний моніторинг, транспортні системи, шляхи сполучення, синергетичний підхід, математичний опис, спостережуваний динамічний процес.

Introduction. Road monitoring is a new definition of a set of works on the analysis of the condition and reliability of individual units and the relevant road transport in general. The condition of the highway is defined as a set of its transport and operational qualities. The reliability of the highway as a complex road transport is its ability to provide safe design traffic at an average speed close to optimal.

Main part.

Interactive monitoring and diagnostics of the condition of highways

Consider the issue of interactive monitoring and diagnostics of roads. Methods for assessing and diagnosing their operational condition are part of the general and special information support, which is part of the information infrastructure of the transport complex. It is also the basis of road infrastructure. Improving traffic safety, speed, comfort and efficiency of passenger and freight transport by road, improving the transport and operational condition of roads, bridges, ensuring the systematic development of the road network depends on sufficient awareness of road users. Therefore, improving technical performance, increasing the competitiveness of roads, promoting socio-economic and environmentally sustainable development of the transport sector is associated with effective road monitoring, which should be the main source of reliable information about the condition of roads at local, regional and national levels.

Today the main problem of the road industry is that the transport and operational condition of roads, bridges and road infrastructure does not provide fast, comfortable, economical and safe transportation of passengers and goods, and therefore accelerated socio-economic, environmentally balanced development of the state, increasing competitiveness. highways to ensure transit traffic and the development of road tourism. Solving this problem at the level of state programs involves the development of road infrastructure in general and its important component – information support for road users, road organizations. This involves, above all, the automation of road management systems, the creation of an electronic database (electronic passports) of roads, the rational planning of their maintenance.

The main disadvantage of the existing information support for road infrastructure development is that the actual accumulation of data on the condition of roads is relatively static. Of course, the development of the road industry requires a dynamic system. Such a system provides for constant monitoring of roads, monitoring of their current condition and identification of trends in its changes.

Today, monitoring of road conditions is limited by the periodicity of scheduled inspections, over time, related to the requests of customers of road works or transport organizations. There is a contradiction between the planned nature, regular periodicity of observations and in general the probabilistic process of constant impact on the state of roads as natural conditions of their operation and the phenomena of general organizational, social nature. The principle of “greatest influence” of control of such a complex organizational and technical system as the highway should work here. Determination and assessment of the state of subsystems, connections and road elements should be carried out in the most informative moments of time $t_k = t_i$, when the impact of this connection on the system during the observation reaches the highest value $q(t)$ – observed dynamic process):

$$\frac{\partial q(t)}{\partial t} \to \max \frac{\partial q(t)}{\partial t}. \quad (1)$$

In fact, it is expensive, its infrastructure is heterogeneous. Accordingly, the road information infrastructure, which includes means of monitoring the condition of roads, depends on and is subject to the structure of telecommunications of computer systems that provide information services. Its main component is telematics. The consequence of this is the need to apply a synergistic approach to solving problems of monitoring subsystems and connections, elements of heterogeneous roads.

Now there is a situation when the practice of creating modern tools for monitoring and diagnosing the condition of roads used to monitor complex objects and systems, preceded the theory. Existing individual road transport information solutions need to be generalized, standardized and unified to define new special requirements for the creation of computer systems and networks in the road sector. One such requirement is the registration and processing of real-time traffic data. Interactive monitoring, the creation of which is the main task of this work, meets these requirements.

This will allow at all levels of road infrastructure to increase the level of information services of road organizations, road users, to avoid existing negative phenomena: failures in traffic organization, unsatisfactory condition of roads, irrational use of funds allocated for repair, operation and maintenance of roads.

The relationship of synergetic integration of telematics systems and mechatronic units of tools and systems with intelligent components of road infrastructure is based on standardization of software and hardware solutions and unification of interfaces and protocols for data transmission based on synergetics, telematics and mechatronics. Mechatronic systems have become a major part of road complexes. Their creation and development correspond to the processes of improvement and optimization of communication routes. Consider the process of observing the state of the highway as the transformation Q of the existing state (set of n variables: $k_1(t), k_2(t),\ldots,k_n(t)$) to a new set of n variables: $q_1(t)$, $q_2(t),\ldots, q_n(t)$. Prototypes $k_i(t)$ of the operator Q are characteristics of the movement in space and time of vehicles, and $q_i(t)$ is a new set of estimates of this movement. Then Q is such an operator that $q_i(t)=Q[k_i(t), t]$, where $k_i(t)$ is a dynamic function that corresponds to the i-th object in the system under study, regardless of its specificity. Interpretation of $q_i(t)$ is the efficiency of the i-th part of the system. Representing this parameter not as productivity or throughput, but as efficiency summarizes the properties of the process of monitoring the condition of roads.

Let L be a set of communication path points consisting of subsets L^{α}, L^{ρ}, L^{γ}, respectively, of the registered values of the current parameters of speed, geometry and communication qualities of communication paths. So, $L = L^{\alpha} \bigcup L^{\rho} \bigcup L^{\gamma}$. Accordingly, the state of the moving object, the process of its movement in the space L of the vehicle and the characteristics of the road environment can be represented as the sum of three operators $S = S' \bigcup S'' \bigcup S'''$, where S, S', S'', S''' – operators of transformation of the observed dynamic processes $k_i(t)$ (observed dynamic process) at a certain point in time t (current characteristics of both the observation process and the state of the communication path).

This creates a kind of chain from the information devices of a single automotive laboratory, internal and external telematics systems to powerful computer systems based on local networks of road organizations, governments and government information systems at all levels of the global network.

Providing reliable and timely information to the management of road organizations, self-government bodies on the condition of roads, highways at the regional and local levels will eliminate the existing negative impact on the functioning of road infrastructure. In general, the process of real-time traffic assessment should be studied and an interactive road registration and visualization system should be developed, as well as road data collection.

This formulation of the research problem requires:

1) analysis of such solutions to assess the quality of roads;

2) determination of the method of monitoring the condition of roads in real time;

3) theoretical substantiation of indirect methods of assessment of transport condition and operational parameters of roads;

4) software and hardware implementation of mobile road monitoring systems, taking into account the experience of a qualified expert (road tester);

5) creation of a synergetic system of maintaining a dynamic automated data bank for the preparation of management decisions in road and transport organizations;

6) performance of technical and economic analysis of the results of the creation of an interactive system for monitoring the condition of roads.

A distinctive feature is the development of a kind of road tester that can be installed on any vehicle connected to the control center – the transport situation center.

A comprehensive generalized assessment of the condition of a part of the highway (sections of the highway) is the weighted average coefficient:

$$K_i = \frac{1}{n} \cdot \sum_j \sum_\gamma \sum_l b^k_{ij\gamma} \cdot \frac{l_{ij\gamma}}{L_{ij}}, \quad (2)$$

where $b^k_{ij\gamma}$ – measured (calculated and normalized and reduced to a single frame of reference) value of the parameter k on the γ-th segment of the road j, which is included in the respective communication routes;

L_{ij} – road length j on the i-th roads;

n is the number of parameters by which alternative roads are evaluated;

i, j, γ – respectively determine: the route variant of the observer system, which is included in the communication routes, the road and the number of its section.

Intellectualization of the observation process, the creation of special equipment that should provide solutions to functional problems of operational diagnostics, are inextricably linked with circuit solutions in this area and digital data processing. A suitable simple mathematical description of such data processing is a linear system with constant parameters, which is the ratio of input and output sequences $x(n)$ and $y(n)$:

$$y(n)=Y\,[x(n),\,t], \tag{3}$$

where Y – is the operator of the transformation of the prototype of the operator $x(n)$ into the image of the operator $y(n)$, defined by the set of n responses in the region T of the current time t.

It should be noted that in this case $Y{:}T \rightarrow T$, where T – is the numerical axis, according to which the time t decreases. In the general case, T is the space in which there are their sets of time responses T_i with a time difference ξTi, and, $\bigcup T_i = T$, but $\bigcap T_i = \varnothing$ (empty set). In real systems, the one-dimensional transformation (3) is transformed into two-dimensional transformations, and in a more general case – into multidimensional transformations of the sequences of signals that are recorded. This is the ratio of the type of convolution:

$$y(n) = \sum_{m=-\infty}^{\infty} h(m)\cdot x(n-m)\ , \tag{4}$$

where $h(m)$ – is the response to one jump or impulse response of the corresponding data recording system.

By analogy with a one-dimensional linear system for a two-dimensional system with the output sequence $y(n_1, n_2)$ and the input data – $x(n_1, n_2)$ is true:

$$y(n_1,n_2) = \sum_{m_1=-\infty}^{\infty}\ \sum_{m_2=-\infty}^{\infty} x(m_1,m_2)\cdot h(n_1-m_1,n_2-m_2)\ , \tag{5}$$

where $h(n_1, n_2)$ – is the impulse response of such a linear system. Then:

$$y(n_1,n_2,\dots,n_i,\dots,n_k) = \sum_{m_1=-\infty}^{\infty}\sum_{m_2=-\infty}^{\infty}\dots\sum_{m_i=-\infty}^{\infty}\dots\sum_{m_k=-\infty}^{\infty} x(m_1,m_2,\dots,m_i,\dots,m_k)\cdot \\ \cdot h(n_1-m_1,n_2-m_2,\dots,n_i-m_i,\dots,n_k-m_k). \tag{6}$$

Accordingly, you can provide the operator with a description of this assessment:

$$y(n_i) \underset{i=1,k}{=} Y_i\left[x(m_i),t\right], \tag{7}$$

where Y_i – is the operator of a k-dimensional linear system for digital registration and processing of vehicle status data.

For the physical implementation of the transformation Y_i it is necessary to fulfill the conditions of physical realization and stability of the created system of monitoring of communication paths: $y(n_0)$ depends only on $x(n_0)$, if $n \leq n_0$. To meet the requirements of system stability, it is necessary to ensure this

$$\sum_{m=-\infty}^{\infty} |h(n)| < \infty\ .$$

In the space-time T, the sequences ti may belong to zones with different differences in time. Thus, the vehicle once existed in the range of T_1, the driver and passenger – T_2, and the vehicle – T_3. You can define the range T_4 with T for which:

$$\forall T_4 \,|\, \exists T_4 = T_1 \bigcap T_2 \bigcap T_3. \tag{8}$$

It should be noted that the prototypes of the observed dynamic process of communication paths are functions of time. The estimate $q(t)$ of the transport system as a whole (the result of general observation) is determined by the coefficient of the operator

$$q(t)=Q\,[h(l),\,t], \tag{9}$$

where $h(l)$ – is a dynamic function of the argument l, which is determined by the time t in the time space T_3.

The operator P is a memory operator, because in this statement are important not only simple definitions or estimates of $h(l)$ at the point $l = l_i$, which corresponds to the point $s = s_i$ and time $t_j \in T$, but also the analysis of the ensemble of values $\{x(t), y(t), z(t)\}$ on the set of reports x_j with its “weight” M_i or (in the general case function) the coefficient of preference. The procedure for scanning paths for $l = l_i$ will look like this:

$$X_j = \frac{\sum_{j=i-1}^{j=i+n} M_i X_j}{\sum_{j=i-n}^{j=i+n} M_i}. \tag{10}$$

To determine the metric of the space of existence of the set of registered functions, the observed dynamic process $x(t)$ should be considered as a set of points x_i on the numerical axis. Consider how the monitoring system (subsystem – "observer") distinguishes these points, determining the process of change of state. For any pair x_i and x_i ($i \neq j$) we can specify such values ξ of x for which the values of x_i become indeterminate or lose their physical meaning. This value determines the threshold for distinguishing states, and for a particular element you can get many values of the thresholds of distinction. The value of the smallest threshold ξ determines the lower limit of the significant difference between the two values of the observed dynamic process $x(t)$ or their existence. This value is the threshold of distinction: $\xi = inf\ sup\ \rho(x_i - x_j)$, для всіх $i \neq j$.

A distinction should be made between physical and consumer discrimination. The accuracy of data conversion is characterized by the "consumer" resolution threshold ξ, and $x(t)$ – the "physical" resolution threshold ξ and characterizes the sensitivity of the system. In this case, the condition for observing the object $\rho\ (x_i,\ x_j) \geq \xi$, because otherwise, it will be impossible to note the change in the state of the observed process.

The considered mathematical procedure of observation of a condition of roads, an estimation of a condition of highways is based on methods of analogies, generalizations, and discrete mathematics for the definition of decisions concerning operative estimation of conditions of movement of vehicles. Solving the problems of observation goes through the stages of operator and graphic description for the theoretical substantiation of indirect methods for assessing the state of transport and operational parameters of roads. Elements of the theory of artificial neural networks, including the theory of fuzzy control, computer modeling should be used for software and hardware implementation of mobile systems for operational monitoring of roads.

It should be noted that there is always the following time sequence ti, during which the instructions of the "control center" t_i, are absent and the control effect $U(t)$ is formed autonomously (onboard the vehicle) by the estimate $Q(t)$:

$$\exists t_i \forall t_i \in T \left| Q(t) = Q_i \left[I(\mathrm{t}), U(\mathrm{t}) \right], I(t_i) = 0. \right. \quad (11)$$

Responsible for a similar transport system connected via a connection, we represent a technical analog of a neural network. Therefore, it is advisable to develop algorithms for the preparation of control solutions at different levels of the transport system, you can cancel the mathematical apparatus of artificial neural networks. From an engineering point of view, artificial neural networks are parallel distributed data processing systems created by simple computing nodes that have the power to accumulate experimental knowledge. Their distinctive feature is training during training *T*. The procedure can be presented as a sequence of steps: calculation of results; comparison with exact values; weight measurement; evaluation of the results of the transformation in accordance with the achievement of the required level of quality, and in the negative case, the repetition of the sequence first (calculation of results).

The creation of an interactive system will be used in the event that its work is not autonomous. It should be based on obtaining data for the formation of a dynamic bank of information about the previous and current state of roads, a network of roads. Such information requires the formulation of an intelligent monitoring system, which is analogous to the relatively simple local systems of interactive monitoring of the condition of roads. This is a task that is solved by the transport situation center with the help of a number of road testers: cars – road laboratories.

Conclusions. The transport situation center can be both the real organization, and the own virtual association of information resources of the road enterprises. The physical basis of such an association will be a distributed computer network of road organizations. The connection of individual computers, local area networks of transport, and road organizations require based on modern computer technology and Internet capabilities. The logical basis of such a heterogeneous computing environment is the information and communication technology of transport process management. To implement the appropriate multilayer systems, it is necessary to solve the problems of creating an information system for monitoring and operational diagnostics of roads.

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