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Neural network modeling of safety system for construction equipment operation in permafrost zone

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Abstract. The problems of neural network modeling of working conditions securing system while operating constructional equipment in permafrost zone are considered. Determining the temperature fields distribution on the soil depth on air temperature in regions with harsh climatic conditions will allow us to solve a number of engineering problems directed to creation of safe working conditions at construction equipment operation. As a first approximation temperature on the surface and in the depth of the upper layer of earth changes under the periodic law, following the change of air temperature during the year. With soil depth increasing the amplitude of temperature fluctuations decreases, but a random component related to weather conditions (the impact of which could be significant) is added to the periodic component caused by change of a season. In the article the mathematical model in the form of Stefan's problem in which boundary conditions on earth surface are replaced with results of measurements is considered. Methods of neural network creation of this problem solution and results of computing experiments are given. The received results show that neural networks are the flexible tool, allowing to consider featuring of a task and all available information. Thus accuracy of results corresponds to accuracy of initial information. The additional information can be effectively used for specification of the required decision.

1. Introduction

The Far North Zone climatic conditions effects the peculiarities of organization and technology of building industry [1,2]. This, in turn, determines the peculiarities of the safe operation of building machines [3].

The introduction of information systems to the risk management in technosphere safety requires the development of corresponding mathematical models allowing to describe fully the physical processes under investigation.

In the building industry mobility of jobs, the variety of building objects, as well as work in the open air makes it difficult to assess the jobs safety. The existing methods of evaluation of the work conditions are focused, mainly, on stationary jobs. The proposed approach allows to combine different information about the system in a neural network model. The approach is also applicable for the decision of problems of labor protection in different industries [4-8].

In many respects the condition of soil determines both the level of safety of construction works, and related working conditions, especially if we take into consideration the regions, where the works are carried out on seasonally frozen or momentarily frozen soils which is typical for certain regions of the Far North and Western Siberia. Determining the distribution of temperature fields on the soil depth from air temperature will allow to solve a number of engineering problems for areas with such harsh climatic conditions. For example, it will help to predict soil condition when placing heavy construction equipment on building sites for ensuring stability while operating hoisting-and-transport machines; And also it will help to plan the start and the finish of carrying out road-building works providing minimization of labor input of excavation and dredging works etc.

Frozen soil excavation complicates carrying out such construction works as site stripping or soil compaction when planning the construction areas; for sanitary-engineering systems; foundation excavation for industrial buildings and constructions; trenching for electrical power pylon installation; well-drilling for pile foundations; earthwork at construction of the main and field pipelines; preparatory, earthwork at construction of highways etc.

The wide range of works is carried out with the use of heavy construction equipment and road and construction machines. For frozen soil excavation expanding equipment capacities are necessary. But it leads to increase in weight and dimensions of construction machines, which in its turn leads to increased risk of carrying out construction works on the short-term and seasonally frozen ground, especially in spring or autumn. Thawing of ice-rich soil is followed by surface subsidence, that’s why there is a threat of destruction of the buildings and engineering constructions while maintaining the frozen basis. All this makes a problem of soil temperature determination at the set depth is actual.

Western Siberia is a big region, and climatic characteristics of Western Siberia change over a wide range, therefore for the description of a general situation, the region is advisable to be represented as a set of restricted areas. For each of them the statistical characteristics of the operating conditions of construction machinery with sufficient precision are constant, including the characteristics of the average daily temperatures and the annual variation.

The minimum air temperature, the temperature of the coldest day, the temperature of the coldest five-day week and the duration of construction machines winter operation are available for design practice, and information about them can be obtained using the appropriate training of the neural network by introducing data on geographical coordinates of an arrangement of point.

Thus, determining the distribution of temperature fields on the soil depth from air temperature in regions with harsh climatic conditions will allow to solve a number of engineering problems directed to creation of safe working conditions at construction equipment operation.

In the book [9] published the results of the work, in the which is the definition of a number of climate characteristics of Western Siberia with the help of neural network modeling on the basis of the package “Essence” created under the scientific guide of Prof. D. A. Tarkhov is made on the basis of the algorithms published in [10]. Such characteristics are: minimum temperature T(min), temperature of the coldest day T(1), temperature of the coldest five-day term T(5) and duration of the cars winter operation period at $T \leq 5°C$. As an initial information these 149 points of meteorological observations were used. This information on the whole region of Western Siberia is interpolated by the perceptron [10].

Under the direction of I. O. Vashurkin and N. N. Karnaukhov [9] on the basis of an Essence package it is created corresponding software, allowing to allocate a zone with similar temperature characteristics, on an example of number of days with daily average temperature less than -5 °C. It is possible giving a task any range of number of days to make such grouping.

It is necessary to make continuous monitoring of temperature of soil for safety of carrying out construction works on the set depth in connection with progressive thawing of frozen breeds that can turn back catastrophic consequences.

Thawing of ice-saturated breeds will be accompanied by sags of a terrestrial surface and development of dangerous cryogenic geological processes: thermokarst, thermoerosion, solt-flucsion, etc. There will be a threat of destruction of buildings and the engineering constructions erected with preservation of the frozen basis [11].

As a first approximation the temperature on a surface and in the heart of the top layer of earth in a year changes under the periodic law, following air temperature change. With depth the amplitude of fluctuations of temperature decreases [3]. However, to the periodic component caused by change of seasons, it is added a random component, connected with the weather phenomena which influence can be essential.

2. Problem of soil temperature determination on the set depth

The problem of definition of the soil temperature changes law on the set depth if the temperature on a surface is known is considered. As a first approximation we neglect changes of distribution of temperature across and heat exchange with air. These specifications can be brought without basic changes in an applied method. Also we pass in the equation and regional conditions to dimensionless sizes, considering as required function and its arguments of the relation of the corresponding sizes to characteristic constants for a task.

The problem statement:

$$u_t = u_{xx}, (x;t) \in (0;1) \times (0;T)$$
$$u(x;0) = \varphi(x), x \in (0;1)$$
$$u_x(0;t) = 0, t \in [0;T]$$
$$u(0;t) = f(t), t \in [0;T]$$

Function *u(t)* in this statement is unknown and is subject to stay.

As the modeling decision function is used

$$R(x,t) = \exp(-k^2 x^2 / (t - t_0)) / \sqrt{t - t_0} \tag{1}$$

As exit parameters k=0,5, t_0= -1

Let us consider for the solution of a task in the form of neural network approach.

$$u(x,t) = \sum_{i=1}^{n_e} c_i e^{-a_i (x-x_i)^2 - b_i (x-x_i)(t-t_i) - d_i (t-t_i)^2} \tag{2}$$

Selection of scales was carried out through minimization of a functional of a mistake which in this task looked like:

$$J_1(\mathbf{w}) + \delta_b J_b(\mathbf{w}) + \delta_d J_d(\mathbf{w}),$$

where

$$\mathbf{w} = (w_1, .., w_{n_e})$$

is a vector of scales of a network;

$$J_1(\mathbf{w}) = \sum_{j=1}^{N} \left\{ u_t(\xi_j, \tau_j) - u_{xx}(\xi_j, \tau_j) \right\}^2$$

is summand agreeable to the differential equation;

$$J_b(\mathbf{w}) = \sum_{j=1}^{N_b} \left\{ u_x^2(0, \tau_j) + (u(x_j, 0) - \varphi(x_j))^2 \right\}$$

is summand agreeable to boundary conditions;

$$J_d(\mathbf{w}) = \sum_{j=1}^{N_d} \left\{ u(0, \tau_j) - f(\tau_j) \right\}^2$$

is summand agreeable to demanded boundary conditions;

$$\delta_b, \delta_d > 0$$

are "penal" multipliers

Let us give some results of calculations for a case N=200, Nb=20, Nd=20, the mistake in a task of initial data from-0.001 to 0.001, number of attempts to add neuron 50, number of neurons 31.

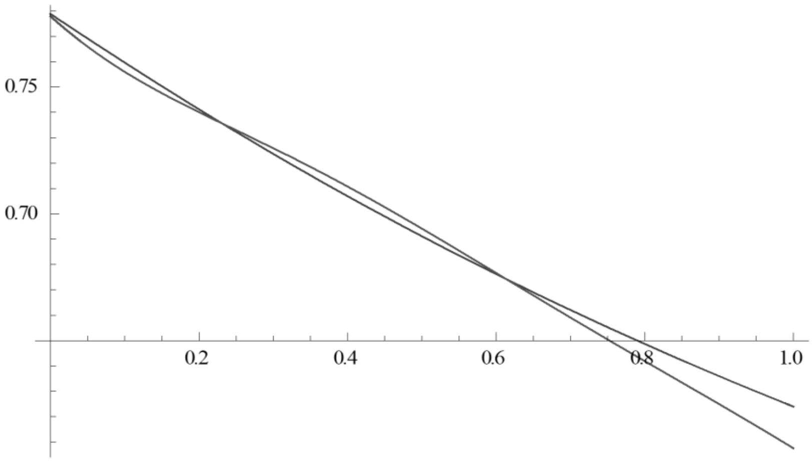

Figure 1. Recovery of the boundary condition. Number of neurons 31

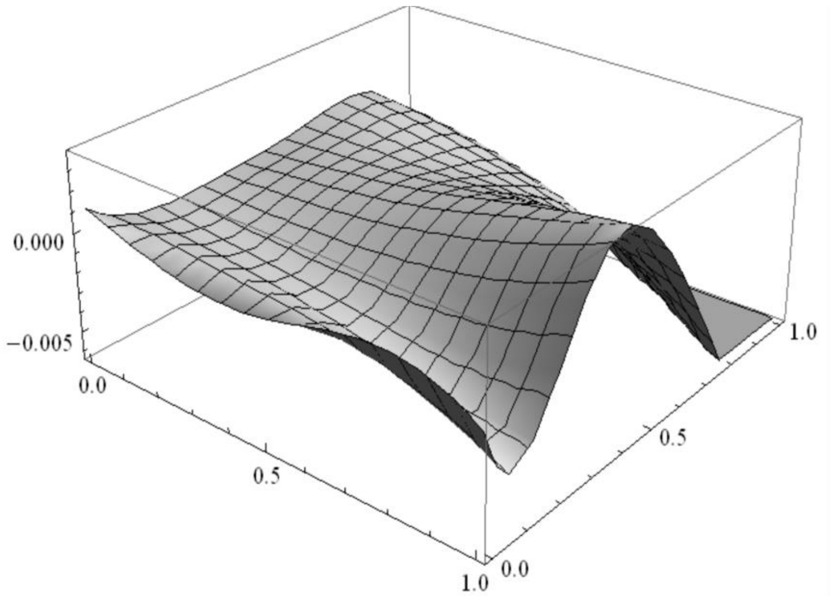

Figure 2. The recovery solution error. Number of neurons 31

Increasing number of neurons up to 41 the following results are received:

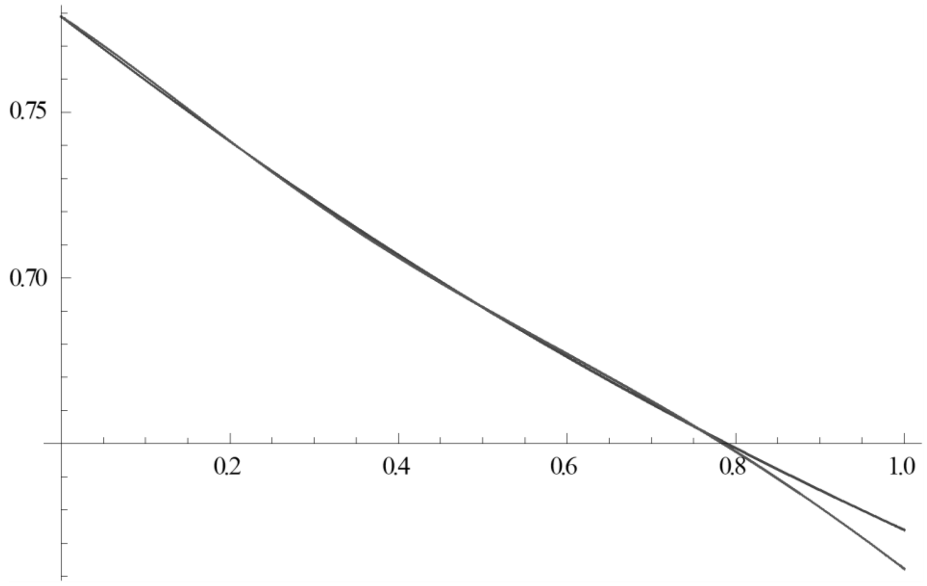

Figure 3. Recovery of the boundary condition. Number of neurons 41

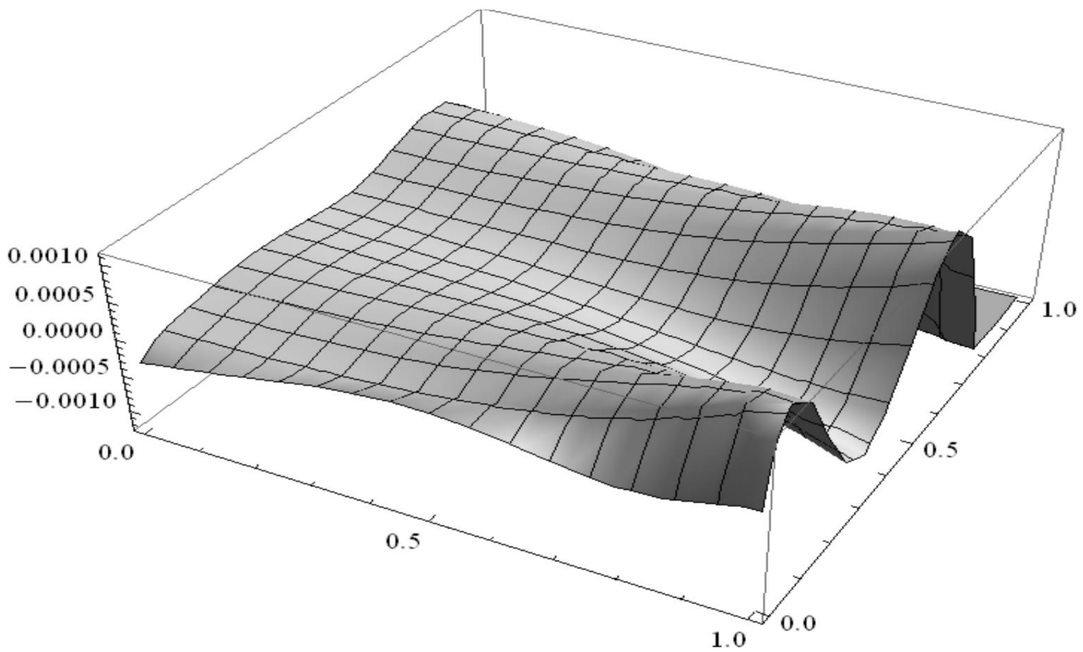

Figure 4. The recovery solution error. Number of neurons 41

This figures shows that even such insignificant additional information on the required decision allows to increase the accuracy of its definition significantly.

If to take 3 points on the right border, then at a zero mistake, number of attempts to add a neuron 50 and number of neurons 41 we receive the following results:

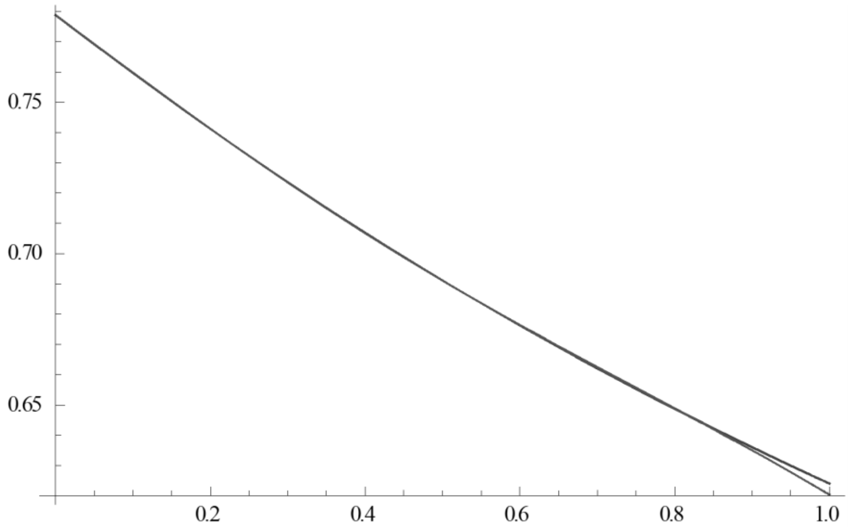

Figure 5. Recovery of the boundary condition.

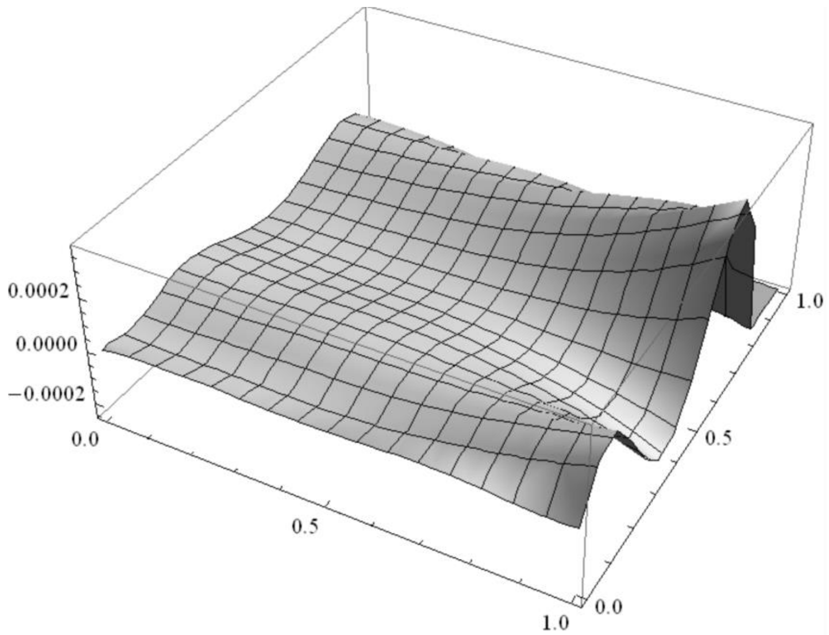

Figure 6. The recovery solution error.

The mistake significantly decreased. This result shows that neural networks effectively use all available information.

If in the previous option to set the required temperature with a random error from -0.1 to 0.1, then results with the corresponding mistake turn out:

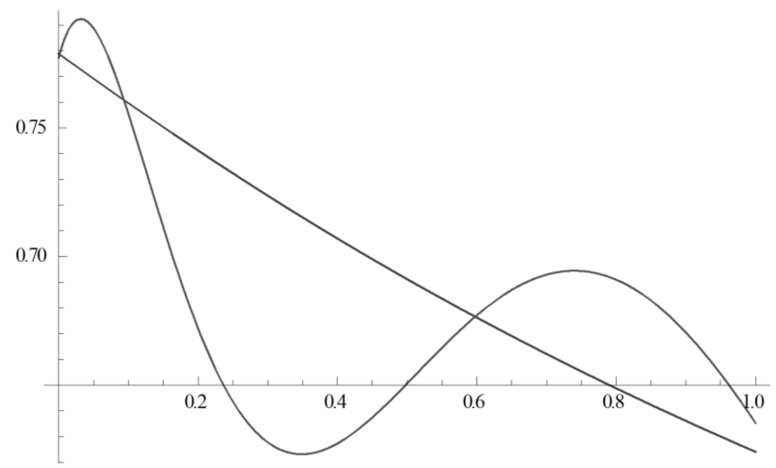

Figure 7. Recovery of the boundary condition.

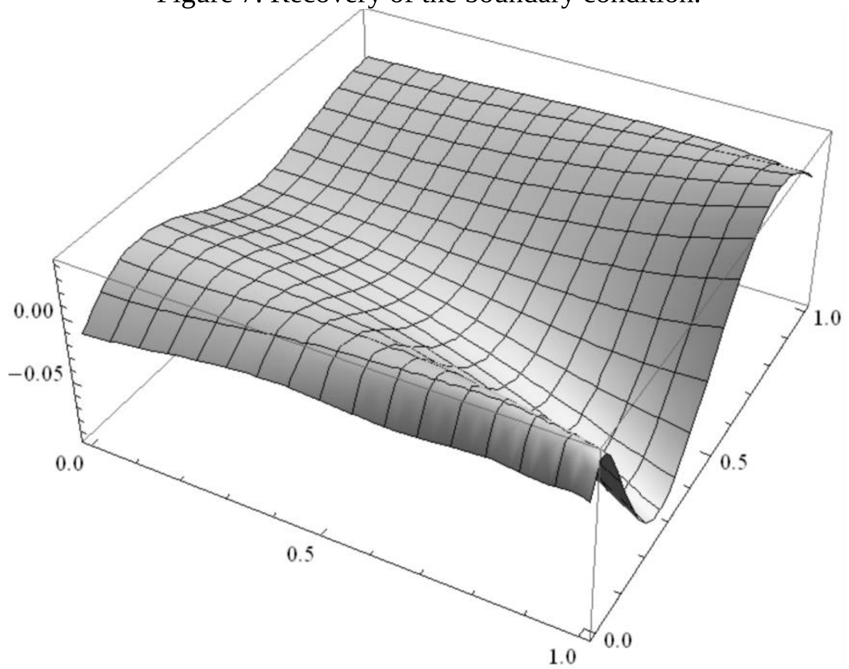

Figure 8. The recovery solution error

3. Summary

The received results show that neural networks are the flexible tool, allowing considering featuring of a task and all available information. Thus accuracy of results corresponds to accuracy of initial information. The additional information can be effectively used for specification of the required decision.

The proposed construction method of the stable neural network models is very effective for the large dimension problems with complex geometry, with inaccurately given parameters, with a diverse update information about the object or the process, for a bad statement problem. Used technologies are the foundation for the construction of hierarchical information-analytical systems of decision making support in construction, in ensuring safe working conditions.

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The approach developed in [10] and [12] is recommended to application for creation of the monitoring climatic phenomena system and providing safe conditions of building works in the Western Siberia.

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