http://dx.doi.org/10.5755/j01.eee.19.7.5179 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 19, NO. 7, 2013

Modeling of Temperature Field Distribution in Mine Dumps with Spread Prediction

Z. Machacek[1], R. Hajovsky[1]
[1]*Department of Cybernetics and Biomedical Engineering, VSB TU Ostrava, 17. listopadu 15, 708 33, Ostrava, Czech Republic*
zdenek.machacek@vsb.cz

***Abstract*—The paper describes mathematical modeling and computation of thermal processes in the environment of mine dumps and industrial waste dumps. The developed program enables testing of various modeling methods and prediction of temperature field distribution and endogenous fires in mine dumps. It is possible to obtain enough information to design a mathematical model for spread prediction and possible dangerous endogenous fires from long time measurements of temperature fields below and above the surface.**

The present methodology is implemented in Matlab mathematical software environment, which enables the design of data files processing and implementation of algorithms for simulation of the temperature field in environment.

***Index Terms*—Dump, measurement system, modeling, metallurgy.**

I. INTRODUCTION

The paper presents an analysis of the research project conducted by different methods and algorithms for modeling of temperature field distribution, prediction and to put it more precisely a mathematical model of thermal processes on the surface and on several levels under the ground pointing to dangerous temperatures inside mine dumps and industrial waste dumps.

Research project is focused to developing an automated system for remote monitoring and visualization of measured data inside mine dumps and industrial waste dumps. The developed system allows very fast information receiving of impending dangerous conditions on the monitored field. It enables perform fast intervention and injection, respectively the automated different mode setting for the installed technology. By the developed system, there is possible to significantly reduce the risk of fires or reduce degradation of technologies installed in the monitored field.

The work uses a measured set of data fields structured in a grid of uniform spaced measurement points in space, which is fundamental for mathematical description of the monitored processes over time and an estimate of further development through the algorithms described below, and other thermal physic rules. For the modeling process the mathematical software environment MATLAB 10 was used.

Manuscript received January 29, 2013; accepted April 24, 2013.
This research was funded by the project of the Technology Agency of the Czech Republic No. TA01020282.

The paper describes implementation of these algorithms, which form the basis for application with a user interface and various important editable parameters of the prediction and interpolation algorithms. The solution contains simulation of thermal processes in the environment, interpolation of measured points, and prediction of temperature processes in future moments [1].

The developed thermal process application is used for indication of all the risks associated with the currently predicted and measured temperature. The sequence of measured temperature fields is displayed in a running slideshow showing a sequence of selected moments in time. There is a graphical output of the temperature correlations in each chosen point in the measured field versus time moments for a description of detection of endogenous fires.

II. IMPLEMENTATION FOR SIMULATION OF TEMPERATURE FIELD PROPAGATION

The progress of the program includes a specific application to generate a thermal model representing thermal processes inside the mine dumps and industrial waste dumps. This application replaces actual measurements in the given locality to test fundamental characteristic processes. The paper presents a simulation of the implemented algorithm which simulates gradual heating in the time domain. The simulation model of the temperature field was created based on data obtained from long-term measurements by 12 temperature sensors distributed in the mining dump field. The measured data represent evaluation of endogenous fire. These evaluated data were statistically analyzed and they were converted into a mathematical model (Fig. 1) for the presentation 3 times copied fire sources with tiny random variations [2] (in time $t=2$).

The simulation of the temperature field in time is implemented in a model map database with defined heating correlations. This mathematical model was created within a dataset in a specific matrix (50x50) where simulating measurement are given for 10 discrete sequentially time moments. This makes a 3-dimensional matrix (50x50x10).

The processing time of the algorithm development for generation of the simulated matrix is sufficiently short, nearly negligible. The elapsed time is 0.108811 seconds.

The basis part of code for the developed algorithm of generation of the temperature field behavior is composed of the absolute value of the sine wave on the y axis, rising and falling on the x axis, at time t linearly increasing, with the random nonlinear temperature disturbance.

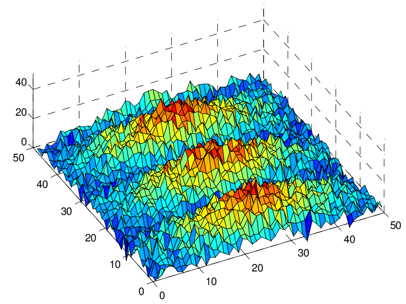


Fig. 1. Graphical example of the simulated temperature fields at defined time.

III. INTERPOLATION ALGORITHM IMPLEMENTATION FOR TEMPERATURE FIELD COMPRESSION

Interpolation is an important part of the process of mathematical analyses of adequate quality and prediction of a sufficiently dense field of the measured data array. For this reason we present an implementation of a temperature field data obtained by approximated interpolation.

Compression may be applied to the given database map of the measured or simulated temperature data. It is possible to modify the parameters and the type of algorithm or the interpolation method.

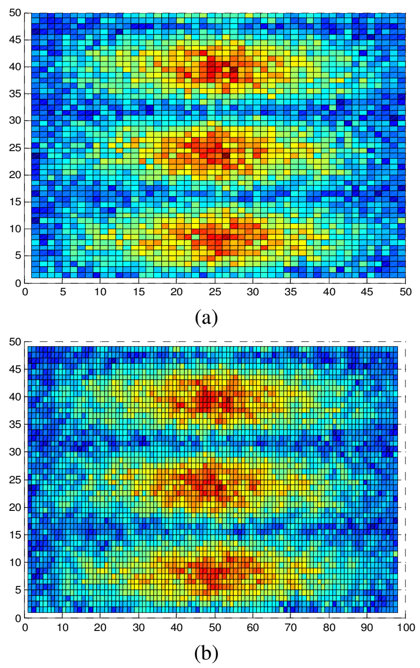


Fig. 2. Graphs of the original temperature field at the given time (a) and the interpolated temperature field (b) with a double compression of the defined temperature points.

The command for the interpolation algorithm with the selected type of approximation, which approximates the points in the two-dimensional array, is defined as follows:

```
Z_new=
interp2(X,Y,Z,X_interp,Y_interp,method).
```

The processing time of the developed interpolation algorithm of the simulated matrix (50x50x10) is 5.506144 seconds. The graphical representation is realized for original and interpolated temperature fields (Fig. 2).

The implemented interpolation method is the two-dimensional function specified by original matrices `X`, `Y`, which represent two dimensional position array and `Z` represents actual temperature value in specific point of array. It is possible to modify the parameters and the type of algorithm or the type of interpolation method based on:

1) Finding of the nearest neighboring point, which is copied to interpolated points `X_interp,Y_interp`;
2) Linear interpolation algorithm, where is computed the interpolated average values between two neighboring points, where new point is `X_interp,Y_interp`;
3) Cubic interpolation algorithm, where is computed the interpolated values in point `X_interp,Y_interp` between neighboring points given by cubic equation;
4) Spline interpolation algorithm is same as cubic interpolation with regular distribution of points.

IV. DESCRIPTION OF PREDICTION ALGORITHM FOR TEMPERATURE FIELD PROCESSES

A prediction algorithm is implemented for approximation of future development in specific temperature points in the dataset. The implemented prediction was tested and contains commands that approximate time processes by a polynomial expression related to a single point correlations in the temperature field. Computation enables specification of approximate values $p_t[x,y]$ of given points $[x,y]$ in a specified future time moment *t* with given coefficients $c_1^n, c_2^{n-1}, \cdots, c_{n-1}$

$$p_t[x,y] = c_1^n[x,y].t + c_2^{n-1}[x,y].t + \cdots + c_{n-1}[x,y]. \quad (1)$$

The described calculation of prediction is executed for all points in the temperature field matrix (50x50), which is measured at 10 time moments. We use a Matlab command: polyval to calculate a given point in a future time moment.

The implemented prediction algorithm contains the parameters, which are essential to correct the predicted value, or the predicted two-dimensional array [3], [4]:

1) Degree of approximated prediction equation;
2) Data array for approximation prediction algorithm;
3) Process character, sharpness, overshoots, dynamics.

The processing time of the implemented algorithm for prediction with 6th order of polynomial equation of the specific matrix (50x50) is 0.280226 seconds.

The command of the prediction algorithm with the selected parameters of approximation, which predicts progressively all points in a defined two-dimensional array, is defined as follows:

```
p = polyfit(t1,z2(t1),r).
```

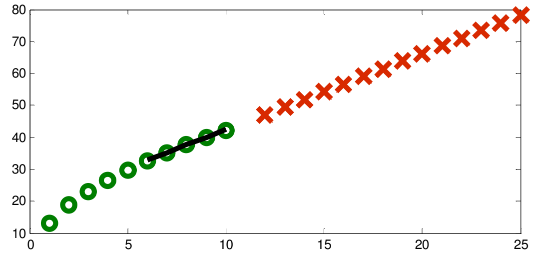
Now, there are still non-resolved correlations of the nearest-neighboring values in the temperature field in the given time point t. This problem needs to be implemented in the trace of future development. The parameter t1 inside the algorithm implementation represents the time interval (measured fields of the moments), which defined the calculation of the polynomials, i.e. temperature correlations in a single measured point in time t.

Another input parameter is z2 (t1) - simulated (measured) temperature at one particular point - selected coordinates x = 25, y = 20 in given time moments 6 to 10. The last input parameter is r, which is the order of the polynomial prediction equation: r = 2;

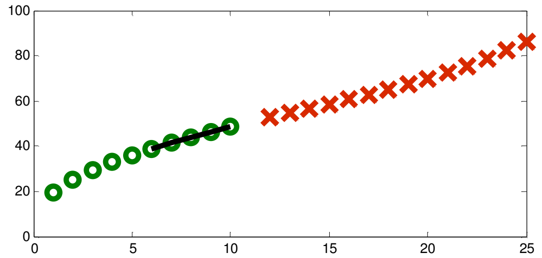
The command for prediction for the given time t1 in the two-dimensional raster-defined field is defined as follows:

```
f = polyval(p,t1),
```

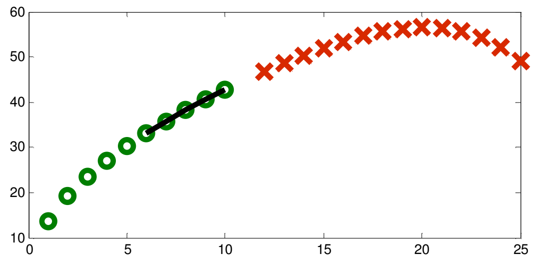
where t1 is the time parameter (time moment in future), which specifies the moment in time for the required predicted temperature value at the given point.



(a)



(b)



(c)

Fig. 3. Graphs of temperature dependences in a defined point [25, 20] in two-dimensional field at time t, which show the measured data, predicted data and the graph trace from results of: (a) 1st order equation; (b) 3rd order equation; (c) 4th order equation.

The next type of prediction for the temperature signal analysis was implemented in a specific prediction model. The implemented evaluation algorithms are composed of Neural Network algorithms with algorithm learning by the back propagation method.

The parameters of the neural network algorithms are user adjustable and some of them are set by studying signal analyses in the temperature characteristic learning mode

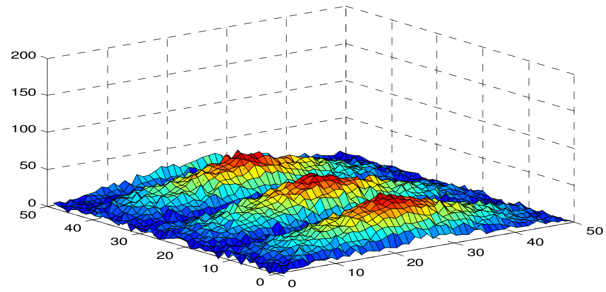
$$V_j = f\left(\sum_{k=1}^{K} w_{Vjk} \cdot X_k\right). \quad (2)$$

Weight of the inputs and limits of neurons in the neural network are set by the training user. Synaptic connections between the input layer and other layers of neural network model are implemented, where the index V indicates outputs of neuron. Coefficient of synaptic weight j indicates the given neuron. Coefficient of synaptic weight k determines which input value affects by weight. The input values $X_k, k \in \{1,2,\cdots K\}$ represents time sequence of measured temperature values in given point of monitored field.

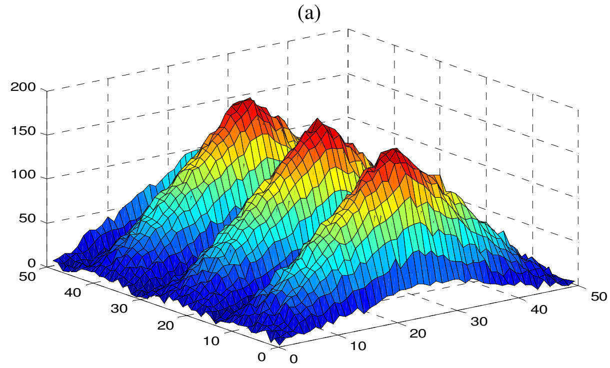
Correct Neural Network parameter setting is conditioned by the user's knowledge of physical rules of temperature spread characteristic behaviors and the possible dangerous endogenous fires. It is possible to recognize some states from recordings of the first problems.

From the graphical correlations follows a problem with regard to a possible distortion of the predicted traces, especially in predictions for remote moment in time. The presented labels in the graphs (Fig. 3) represent:

- ° ... measured (simulated) temperature values in time moments t = 1-10 at one particular point [25, 20],
- \- ... the input measured (simulated) temperature values in time moments t = 6-10 at one particular point [25, 20] for generating a prediction algorithm,
- x ... predicted temperature values in the future time moments t=12–25 at one particular point [25, 20].



(a)



(b)

Fig. 4. Graphs of two-dimensional predicted temperature field (a) in time t=10; (b) in time t = 25.

The prediction algorithm was used and tested for future temperature process definition in the whole analyzed temperature data array. The display only includes one defined predicted time moment t implemented and tested using the same principles and commands as described in the text above. The processing time of the developed algorithm for prediction of the future temperature process of the specific matrix (50x50) is 1.556904 seconds.

The graphs show the actual measured temperature field (Fig. 4a) and the predicted temperature field (Fig. 4b) at defined intervals.

V. PREDICTION APPLICATION AND MEASUREMENT DEVICE DESCRIPTION

The developed application (Fig. 5) is usable for predicting and displaying the time characteristics of thermal processes on the surface of sensing the temperature inside of mine dumps and industrial landfills. The application contains mathematical model and it allows the database storing of the data field in a two-dimensional measurements in the probes, which can be stored in layers by given methods and algorithms presented in the paper. The development of prediction algorithms is based on the collection of statistical measurement in the past.

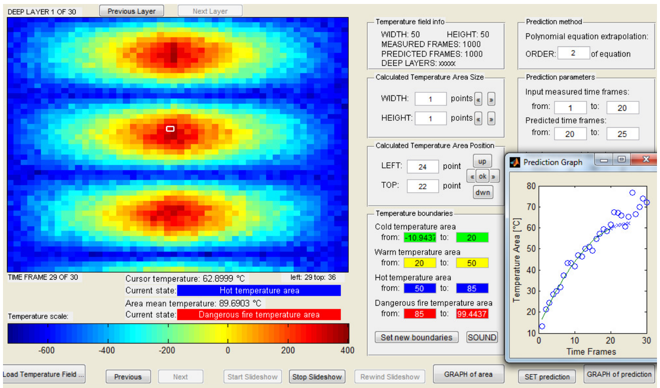


Fig. 5. Developed application temperature field prediction in dump area.

A special technology for collecting heat on mine dumps affected by the thermal process has been developed and constructed in the context of the research activities in the field of modeling and prediction of thermal processes on mining dumps. The developed system (Fig. 6) is composed of measurement part and computation part. The measurement part is divided into two main parts: the primary heat collector, which is made of a steel cylinder of diameter of 30cm and length of 5m. Inside the cylinder there are three partitions divided into four equal compartments. Above each partition there is a temperature sensor PT 100, and more temperature sensors are placed at the input and output to the receiver. The medium flows through a thin tube in the middle of the receiver to the lower chamber and then through the openings in the bulkheads gradually into the upper chamber and the primary heat exchanger [5].

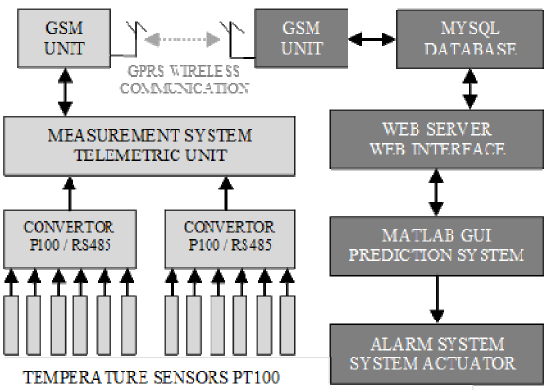


Fig. 6. Diagram of developed measurement system in dump area.

The secondary circuit is formed by a complex technology for cooling medium temperature.

The computation part is connected by wireless communication data transfer with measurement part. This part is usable for data processing, user presentation, prediction dangerous states in the temperature field.

VI. CONCLUSIONS

The purpose of the paper was to develop and verify the possibility of simulation and prediction of thermal processes in the environment of mine dumps and industrial waste dumps. It focused on a description of the possibility, parameters and methods usable for modeling of thermal processes from measured or simulated data of temperature fields below and above the surface in a defined sequence of time moments. This solution is very important for detection of dangerous endogenous fires, which can spread inside the mines. The developed methodology combines theoretical physics knowledge and statistical methods usable in Mathematical software Matlab.

Quite clearly the designed model of thermal progress is a functional and very useful instrument for warning against any spreading endogenous fires. The model implementation is adaptable to various measured data of thermal field progress by user defined parameters of prediction through the definition of the polynomial equation. The project simulation results are prepared for development of a more user friendly application with implementation of other methods of prediction. In this moment, there is prepared the process for automated comparison of measured and predicted field values for evaluation of prediction models.

The described technology and all research work in the field of modeling and prediction of thermal processes is very unique not only in the Czech Republic. The Moravian-Silesian region has several thermally active mine dumps, which must be subject to long-term monitoring and forecasting of dangerous dump endogenous fires over longer time horizons.

REFERENCES

[1] Z. Machacek, "Analysis and Elimination of Dangerous Wave Propagation as Intelligent Adaptive Technique", in *Proc. of the 3rd International Conference ACIIDS*, 2011.

[2] L. Lixin, P. Revesz, "Interpolation methods for spatio-temporal geographic data", *Computers, Environment and Urban Systems*, Elsevier, vol. 28, no 3, pp. 201–227, 2004. [Online]. Available: http://dx.doi.org/10.1016/S0198-9715(03)00018-8

[3] S. Ozana, Z. Machacek, "Implementation of the Mathematical Model of a Generating Block in Matlab&Simulink Using S-functions", in *Proc. of the Second International Conference on Computer and Electrical Engineering (ICCEE)*, 2009, pp. 431-435.

[4] R. Hajovsky, S. Ozana, P. Nevriva, "Remote Sensor Net for Wireless Temperature and Gas Measurement on Mining Dumps", *Recent Researches in Applied Informatics and Remote Sensing,* WSEAS Press, pp. 124–128, 2011.

[5] R. Hajovsky, M. Pies, "Complex Measuring System for Longtime Monitoring and Visualization of Temperature and Toxic Gases Concentration", *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering)*, no. 6, pp. 129–132, 2012.