Real-time emergency forecasting technique for situation management systems

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Abstract. The article describes the real-time emergency forecasting technique that allows increasing accuracy and reliability of forecasting results of any emergency computational model applied for decision making in situation management systems. Computational models are improved by the Improved Brown’s method applying fractal dimension to forecast short time series data being received from sensors and control systems. Reliability of emergency forecasting results is ensured by the invalid sensed data filtering according to the methods of correlation analysis.

1. Introduction
Emergency forecasting is used to prevent and mitigate the consequences of natural hazards and man-caused disasters. The emergency forecasting techniques include long-range forecasting techniques and short-term forecasting techniques. Both of them are based on the computational models where input data sets are sensed data, Earth remote sensing data, digital aerial mapping and photography, etc. The examples of these computational models are:

- the model of the consequence analysis for chemical emergencies [1];
- the early fire detection model [2]
- the scenario-based model for earthquake emergency management [3]
- the model of continuous dense gas leakage [4];
- the model of river flood monitoring [5].

The emergency forecasting techniques based on long-range and short-term prediction models are the essential part of situation management systems that provide embedded decision support mechanisms with data visualization by geographic information system (GIS) technologies [6, 7], such as high probability emergency areas, impact zone mapping, emergency behavior and various scenarios of emergencies.

Short-term forecasting techniques provide the opportunity to analyze high-speed hazardous processes like emergencies in real-time. Short-term prediction models estimate the threat probability of emergency or evaluate the consequence of accidents. Basically, short-term prediction models in contrast to long-range prediction models use current (actual) data being sent by various sensors and control systems. In the Russian Federation, the computational models based on the forecasting techniques (basic models) are developed by the branch public institutions and approved by the Emergencies Ministry of Russia. These basic models are:
• technique for estimation flooded areas caused by hydrodynamic accidents [8];
• technique for forecasting the scale of high-toxic contamination caused by accidents (disruption) of chemical hazardous facilities and transport [9];
• technique for estimation the consequences of accidental detonation of fuel-air compositions [10].

In this work, the authors developed the real-time emergency forecasting technique that allows increasing accuracy and reliability of forecasting results of any emergency computational model applied for decision making in situation management systems.

2. The technique for emergency forecasting
Proposed real-time emergency forecasting technique for situation management systems consists of the following steps:
• data acquisition from various sensors and control systems;
• invalid raw sensed data filtering;
• short-term time series sensed data prediction;
• emergency forecasting by basic models using received and predicted sensed data values;
• simulation results visualization using received and predicted sensed data.

Figure 1 shows the diagram that describes the implementation of the real-time emergency forecasting technique according to its steps.

![Diagram of real-time emergency forecasting technique](image)

**Figure 1.** Real-time emergency forecasting diagram.

Step 1 includes data acquisition from various sensors and control systems, such as water level sensors, pressure meters, gas sensors, meteo sensors, etc.

Step 2 includes invalid sensed data filtering by the methods of correlation analysis. The filtering is necessary because sensed data acquisition from remote systems is performed commonly without fault monitor and, therefore, sensed data may be distorted during the long distance transmission.
Step 3 includes short time series sensed data prediction. The forecasting allows detecting alarm conditions before accident events if predicted data values lie outside high and low-limit values associated with an observed hazardous process.

Step 4 includes emergency modelling and forecasting of the accidents’ consequences according to the basic computational models using received and predicted sensed data.

Step 5 includes the visualization of simulation results by emergency mapping. The graphic emergency model represents the impact zone of emergency (polygons) where current and predicted impact zones are separated from each other by map layers.

Suggested methods and algorithms are described in sections 3-5 of the present paper.

3. **Invalid sensed data filtering by the methods of correlation analysis**

Input data of correlation processing model is sensed data \( Z \) received from various sensors \( s(z_1, \ldots, z_j) \). Received data sets of various sensed data \( Z \) generate sets of input parameters \( P \) which allow one to detect the emergency, evaluate its behavior and consequences.

In this work, let us apply the methods of correlation analysis to detect validity and reliability of sensed data values \( Z \) by mutual correlation between data values being sent by various sensors. For this, sensors are grouped into \( G(s_1, \ldots, s_i) \) where sensed data values \( s_1, \ldots, s_i \) correlate with each other. The strength of correlation between one-grouped sensed data values \( Z \) is estimated by the value of pair Pearson correlation coefficient \( r_{yx} \). Correlation between sensed data values \( Z \) being sent by sensors \( s_1, \ldots, s_i \) should be recorded as a correlation matrix (figure 2).

![Figure 2. Correlation matrix.](image)

Time series sensed data aggregation is needed before reliability analysis to a uniform data points range of all received time series data sets where time series range should be equal to a minimal range among all data sets. Thus, time series with small range should be enlarged and data points should be aggregated. Linear interpolation is used to recover missing sensed data values. Then, calculating pair Pearson correlation coefficient \( r_{yx} \) for each pair from correlation matrix is needed. If \( r_{yx} > 0.3 \), the pair should be excluded from the matrix. Excluded pairs of sensed data values are invalid and are not used in emergency modelling.

4. **Short time series forecasting method**

In this work, let us propose describing a prediction model by the algorithm based on the Improved Brown’s method applying fractal dimension to forecast short time series [11].

The suggested method of sensed data analysis and short-term data prediction consists of the following steps:

- time series analysis for stationarity/non-stationarity;
- maximum forecasting time-frame estimation;
- time series forecasting of the observed hazardous process or facility according to determined forecasting time-frame.

Time series analysis for stationarity/non-stationarity can be performed by splitting the existing time series into starting sections and finding the conditions where the following equalities exist for each section \( \tau = 2, n \):
• equality of average values $M(2)=M(3)=...M(n)$;
• equality of variance values $D(2)=D(3)=...D(n)$.

Allowable deviation of the average values and the variance values from their previous values for stationary processes is 5%.

Maximum forecasting time-frame estimation of the observed hazardous process or facility (emergency parameters) can be calculated by the method [12] where time-frame value is equal to the long-term memory of existing time series.

Time series forecasting of the observed hazardous process or facility according to determined forecasting time-frame should be performed by the calculation formula of the Improved Brown’s method [11]:

$$z_i = (2 - \tilde{H})z_{i-1} + (\tilde{H} - 1)z_{i-2}$$ \hfill (1)

In expression (1), $\tilde{H}$ is the averaged Hurst exponent.

5. Emergency forecasting and results visualization

Basic models are represented by the complex function of parameters, which values are received from sensors or control systems. The function detects the fact of emergency or evaluates the damage caused by emergency:

$$f(P) = \{y \in Y\}$$ \hfill (2)

In expression (2), $P$ is the vector of sensed data values produced by invalid sensed data filtering $Z$, $y$ is the observed hazardous process or facility state, such as «NORMAL», «ATTENTION», «ALARM», or $y$ is the vector of values obtained by damage (or potential threat) evaluation $y(y_1,...,y_n)$. If basic model estimates the emergency area (break of a dam probability and possible flooded area [8]), the visualization of simulation results may be represented by the set of polygons $S(s_1,...,s_n)$ produced by GIS:

$$S = f(y).$$ \hfill (3)

Besides, a basic model can perform emergency forecasting that includes the behavior and the scenario of the emergency within a certain time-frame. In this case, the vector $y$ includes the set of observed hazardous process or facility states according to forecasting time-frames. Results visualization of this model should be represented by vector $M$ which includes various states $s$ of the observed hazardous process or facility $M(S_1,...,S_r)$. The example is the evaluation model for forecasting the scale of high-toxic contamination caused by accidents (disruption) of chemical hazardous facilities and transport [9].

Figure 3 shows the steps of emergency forecasting and results visualization according to the suggested technique.

![Figure 3](image)

Figure 3. Emergency forecasting and results visualization diagram.

By short-term time series prediction according to the Improved Brown’s method, set $\hat{P}_1,...,\hat{P}_k$ is calculated, where the range of each element is equal to the forecasting time-frame. Both current values $P$ and predicted values $\hat{P}$ are used by basic models to forecast the emergency. In this case emergency visualization and simulation visualization with forecasting results are represented by vector $M$ that
includes current state of the observed hazardous process or facility $S_p$ and various predicted states of the observed hazardous process or facility $M_p(S_{\hat{p}_1},...,S_{\hat{p}_k})$ where each state is produced by predicted sensed data values $\hat{P}$. Basic models that can forecast the emergency within a certain time-frame, predicted data $\hat{P}$ preprocessing is needed. For this, the length of time series $\hat{P}_1,...,\hat{P}_k$ should be equal to time-frames of basic model $\hat{P}_1,...,\hat{P}_k$. Besides, time series $\hat{P}$ should have a uniform data points range at the stage of input data filtering by the range enlargement or applying linear interpolation to recover missing data points. Then the modelling stage should be performed where the results contain the current state of the observed hazardous process or facility $S_p$ and various predicted states $M_1,...,M_t$. These observed hazardous process or facility states produce vector $M_{\hat{p}}$ which contains states $S_{\hat{p}_t}$ according to time-frame $t$. Thus, results visualization is represented by vector $M(S_p,M_{\hat{p}}(S_{\hat{p}_1},...,S_{\hat{p}_k}))$.

Figure 4. Emergency forecasting and results visualization diagram using predicted sensed data values.

6. Conclusion
The proposed real-time emergency forecasting technique allows one to increase accuracy and reliability of forecasting results of any emergency computational model applied for decision making in situation management systems. Computational models are improved by the Improved Brown’s method applying fractal dimension to forecast short time series data being received from sensors and control systems. Reliability of emergency forecasting results is ensured by the invalid sensed data filtering according to the methods of correlation analysis. The technique allows one to develop GIS-interface of the situation management system which provides embedded mechanisms to visualize and analyze current and predicted emergency impact areas (polygons) according to actual data being sent by various sensors or control systems in real-time.

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