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ACTIVE MONITORING AND DECISION MAKING PROBLEM

Sergey Mostovoi, Vasiliy Mostovoi

Abstract: Active monitoring and problem of non-stable of sound signal parameters in the regime of piling up response signal of environment is under consideration. Math model of testing object by set of weak stationary dynamic actions is offered. The response of structures to the set of signals is under processing for getting important information about object condition in high frequency band. Making decision procedure by using researcher’s heuristic and aprioristic knowledge is discussed as well. As an example the result of numerical solution is given.

Keywords: math model, active monitoring, set of weak stationary dynamic actions.

ACM Classification Keywords: I.6.1 Simulation Theory.

Introduction

The distinctive feature of seismic monitoring is the particular, seismic frequency range, encompassing infrasonic and low range of a sound spectrum. The characteristics of each monitoring object are slowly varied in time, but at the same time sometimes processes might be occurred is too rapid. The seismic monitoring deals with the large size objects, down to the sizes of a terrestrial Globe. Because of mankind anxiety on possible earthquakes, the extremely passive monitoring has a deep history, but at latest time the active monitoring is often used. The active monitoring is such an experiment, which one is connected to generation of sounding signal of a different type, both on a spectral band, and on duration and power, down to atomic explosions. But in active experiment only monitoring approach enables to obtain ecological pure result, i.e. without any of appreciable influencing on an environment. Monitoring is a set of regime observations, and condition of observations and the characteristics of sounding signal depend on the purposes of given investigation. There are many such purposes, but, from our point of view, we select two basic one. It is dynamics of variations happening in investigated object, and it is detail of estimations, which characterise this object. Despite of large discrepancy of these two purpose, the approaches both to experimentation and to processing receivable data are very close, as well as problems, originating at it.

To problems, first of all from the ecological point of view, it is necessary to refer necessity to realize active monitoring of investigated object by low-power signals, commensurable with a level of a natural background. This circumstance results that the estimation of sounding signal parameters, passing the studied object, i.e. signal response of an investigated system on a sounding signal, is hampered because of a low signal-noise proportion.

Therefore there is a necessity for the special conditions of experiment and applying special, sometimes very composite, signal processing procedures of an investigated system response. The used above words "the regime observations" consider rigid stability in implementation of a condition. It means stability of monitoring time characteristic and parameter stability of a sounding signal, i.e. invariance of its spectral characteristic. With evidence it is clear, that always there is an extreme accuracy of arguments describing a signal and arguments temporary experiment providing. In this article the problem is put: when and to what arguments the instability is essential, in what it results, and how to eliminate its influencing, if it is possible?

First of all, it is necessary to construct a mathematical model of experiment, in which one the most essential moments of monitoring process would be reflected, including both processes, and, accompanying this process background noise, and natural hum noise. The prior knowledge of noise stochastic process will allow largely weakening its influencing on deriving of estimation obtainment of process arguments, which one is perceived as a useful signal. This slackening is reached by optimization of processing procedures, which is taking into account prior statisticians of noise stochastic processes.

In a series of treatises [1-4] the separate aspects of a reduced problem were regarded. Into the given paper there is an attempt to summarize earlier reviewed the approach to procedure modeling of active experiment, analysis of experiment parameters instability influence and optimization of procedure processing of observed data, by yardsticks taking into account the characteristics of a natural background noise, instability of sounding signal parameters and consequences caused by this instability.

The Mathematical Model of Active Monitoring

The math model of i-th experiment in a serial from M -th ones is proposed. In active monitoring serial can be introduced as follows:

$$y_i(t) = S\left(t, \tau_i, \vec{h}_i\right) * H(t) + n_i(t), \quad t \in \left(\tau_i, \tau_i + T\right), \tag{1}$$

Where i is number of experiment, $y_i(t)$ - response of environment to an sound signal $S\left(t, \tau_i, \vec{h}_i\right)$, depending from vector of parameters $\vec{h}_i$, which one is convoluted with reacting of environment $H(t)$ on a delta-function signal $\delta(t)$, $n_i(t)$ an additive noise accompanying experiment, T - duration of one experiment, $\left(\tau_i, \tau_i + T\right)$ - time period of i -th experiment conducting of, and $*$ - a convolution operator symbol. The experiment is constructed in such a manner that energy of a signal, registered by sensors, $E\left[\ S\left(t, \vec{h}_i\right) * H(t)\ \right]$ and energy of a natural background $E\left[n_i(t)\right]$ are commensurable in the selected metric, it means, that influencing of experiment on a state of the environment is negligible. In the pattern that circumstance is taken into account, that the non-linear phenomena in experiment can be neglected, a linear routine of the specification statement of interplay of environment and exploring signal by the way convolutions therefore is selected. Let's mark, that the convolution is described by following integral:

$$S(t) * H(t) = \int_0^{\infty} H(\tau) S(t - \tau) d\tau, \tag{2}$$

The full experiment is defined by following model

$$y(t) = \sum_{i=1}^{M} y_i(t) \tag{3}$$

As a time of experiment T we shall consider the time for which one the reaction level of environment to an exploring signal becomes less then some level ε, which one can be selected depending on a level of a natural background. For example, in the metric $C_{(\tau_i + T, \tau_i + \Gamma)}$; $\Gamma >> T$ is instituted from a condition:

$$\max(y_i(t)) \le \varepsilon \; ; \; t \in (\tau_i + T, \tau_i + \Gamma) \quad \text{for } \forall \tau_i \tag{4}$$

Certainly ε, and after it and T as well, is exclusively selected by the feeling of explorer heuristics, his point of view to experiment and a priori estimations of a noise $n(t)$ power. As it was noted, the monitoring guesses a serial from M experiments, i.e. $i = \overline{1, M}$.

The Model of an Exploring Signal

Let's consider, that the signal $S(t, \vec{h}_i)$ depends on the vector of parameters $\vec{h}_i = \{h_{i1}, ..., h_{iN}\}$, which components are define the shape and energy of signal. It is naturally to consider that a signal is physically realizable, i.e. to be fitting two conditions: causality and stability. The same conditions are natural to the reacting of the environment $H(t)$ as well.

$$S(t, \vec{h}_i) = \begin{Bmatrix} S(t, \vec{h}_i), t \ge 0 \\ 0, t < 0 \end{Bmatrix}; \qquad \int_0^\infty \left(S(t, \vec{h}_i)\right)^2 dt < \infty \tag{5}$$

Causality means, that if the signal has been started at the moment τ_i, it means that the experiment has begun at this moment and up to this moment the signal did not exist.

$$S(t, \vec{h}_i, \tau_i) = \begin{Bmatrix} S(t - \tau_i, \vec{h}_i), t - \tau_i \ge 0 \\ 0, t - \tau_i < 0 \end{Bmatrix} \tag{6}$$

In a condition of causality we at once consider also a condition of stationarity that is reflected in the dependence of a signal on a difference of time t and the signal start moment τ_i

The stability means, that for any value ε of an energy level in the metric L_2 there is such value of T, that

$$\int_T^\infty \left(S(t, \vec{h}_i)\right)^2 dt < \varepsilon . \text{ for } \forall h_i \tag{7}$$

The last circumstance allows to determine duration of one experiment T, for this purpose it is necessary, that the level ε was less or much less then the energy level of a natural background.

It is possible to consider τ_i as one of the component (for example, with a zero subscript) of a vector of arguments, which are defining the signal and which are non-linear - including in the pattern of a signal. The duration value of T is a value of deterministic argument, for example, which is equal to the last component of vector $\vec{h}$. Let's try to represent other non-linear arguments of a signal. The signal can be introduced as a linear combination of known functions (for example, fragment of a vector of orthogonal functions $\{\varphi_k(t - \tau_i, k \cdot \omega_{0i}) \chi(t, \tau_i - \psi_i, \tau_i + T)\}$, $k = \overline{1, N}$ at an interval of length T.

$$S(t, \vec{h}_i, \tau_i) = \sum_{k=1}^{N} h_{ik} \varphi_k(t - \tau_i, k \cdot \omega_{0i}) \chi(t, \tau_i - \psi_i, \tau_i + T) \tag{8}$$

Here is ω_{0i} - a sample unit of random argument ω_0, which defines system of functions $\vec{\varphi}(t, \tau, \omega, \psi)$, and ψ is the applicable phase for this system

$$\vec{\varphi}(t, \tau, \omega, \psi) = \{\varphi_k(t - \tau, \omega \cdot k) \cdot \chi(t, \tau - \psi, \tau + T)\}, \quad k = 1, ..., N \quad . \tag{9}$$

Here is characteristic interval function $\chi(t, \tau - \psi, \tau + T)$, which is also a non-linear characteristic of the signal model, as well as argument T,

$$\chi\left(t,\tau_i-\psi_i,\tau_i+T\right)=\begin{Bmatrix}1, & t\in\left(\tau_i-\psi_i,\tau_i+T\right), \\ 0, & t\notin\left(\tau_i-\psi_i,\tau_i+T\right);\end{Bmatrix}.$$

Let's consider argument ω_0 as one more component of arguments vector $\vec{h}$, namely h_{N+1}. Then ψ - h_{N+2}, and T we shall consider as a h_{N+3} component of vector $\vec{h}=\{h_k\}, k=0,\dots,N+3$.

In this case a sound signal in experiment with number i will be $S\left(t,\vec{h}_i\right)$.

So, the signal model is a random function which is supposed to be physically realizable and a stationary, which one is completely instituted by a random vector $\vec{h}$, N parameters of which one are linearly entered into the model.

Under consideration is a case, when set of vectors $\vec{h}_1,\dots,\vec{h}_M$, are sampling from set of probable values of vector $\vec{h}$ with a priori known distribution $P(\vec{h})$. It means, that the stochastic nature of process $y(t)=\sum_{i=1}^{M}y_i(t)$ is defined by a random vector $\vec{h}$ and stochastic additive noise $n(t)$. As a determined component into this process is a response of environment $H(t)$ on a testing signal such as a delta-function. This response contains the environment information. As fluctuations of arguments of an exploring signal is determined and linearly, through the convolution equations, are connected to a signal $s(t,\vec{h}_i)$, registered by sensors on an exit of an observation system, that, allowing identifications (2) for a convolution $*$, we shall obtain

$s(t,\vec{h}_i)=S(t,\vec{h}_i)*H(t)$ and

$$y_i(t)=s\left(t,\vec{h}_i\right)+n_i(t),\quad t\in\left(\tau_i,\tau_i+T\right),\tau_i=h_{i0},T=h_{N+3}. \tag{10}$$

Hereinafter we shall esteem only response of environment $s\left(t,\vec{h}_i\right)$. Let's decipher separated values of a vector of components, defining both signal $S(t,\vec{h}_i)$ and response of environment $s\left(t,\vec{h}_i\right)$. First of all, try to separate arguments which are included linearly and non-linear into the model.

$$S(t,\vec{h}_i)=\left(\sum_{k=1}^{N}h_{ik}\varphi_k(t-h_{i0},h_{i,N+1}\cdot k)\right)\cdot\chi\left(t,h_{i0}-h_{i,N+2},h_{i0}+h_{iN+3}\right) \tag{11}$$

τ_{i0} is the component of vector $\vec{h}_i$ with zero index, ω_{i0} - $N+1$, and T - $N+2$ -th of a component. Function vector $\vec{\varphi}(t,\vec{h})=\{\varphi_k(t-\tau,\omega\cdot k)\cdot\chi\left(t,\tau-\psi,\tau+T\right)\},\quad k=1,\dots,N$ (12)

might be set of convenient for approximation an exploring cue of functions or piece orthonormalized on a spacing $(0,T)$ of basis functions. The approximating of an exploring signal in seismic survey by the way of damped sine wave can be regarded as the example

$$S(t,\vec{h}_i)=\theta_i\cdot\exp\{-\alpha_i t\}\cdot\sin\{\omega_i\cdot(t-\tau_i)\}\cdot\chi\left(t,\tau_i-\psi_i,\tau_i+T\right) \tag{13}$$

In this case vector of free parameters of the pattern, which defines the signal, is $\vec{h}_i=\{h_{ik}\}=\{\tau_i,\theta_i,\alpha_i,\omega_i,\psi_i,T\},\quad k=0,\dots,5$ and has only five components, from which only the second one h_{i1} is entered into the model linearly. In general, and relevant for practice of seismic sounding case, the signal is represented by the way of approximating piece of its expansion in a series of orthonormalized base, as in the expression (6). The response of environment in i th experiment will be

$$s(t,\vec{h}_i)=\left(\sum_{k=1}^{N}h_{ik}\left(\int_{\tau_i}^{\tau_i+T}\varphi_k(t-\tau_i-\tau,\omega_i\cdot k)\cdot H(\tau)d\tau\right)\right)\cdot\chi\left(t,\tau_i-\psi_i,\tau_i+T\right) \tag{14}$$

Taking into account above mentioned result of a serial from M trials $y(t)$ becomes:

$$y(t)=\sum_{i=1}^{M} y_i(t)=\sum_{i=1}^{M} S\left(t,\vec{h}_i\right)*H(t)+n_i(t)=\sum_{i=1}^{M}\left(\sum_{k=1}^{N} h_{ik}\left(\int_{\tau_i}^{\tau_i+T}\varphi_k(t-\tau_i-\tau,\omega_i\cdot k)\cdot H(\tau)d\tau\right)\right)$$
$$\cdot\chi\left(t,\tau_i-\psi_i,\tau_i+T\right)+n_i(t),\quad t\in\left(0,M\cdot T\right)$$
(15)

Let's define:

$$\tilde{\varphi}_k(t-\tau_i,\omega_i\cdot k,\psi_i)=\chi\left(t,\tau_i-\psi_i,\tau_i+T\right)\int_{\tau_i}^{\tau_i+T}\varphi_k(t-\tau_i-\tau,\omega_i\cdot k)\cdot H(\tau)d\tau\ . \quad (16)$$

With allowance for (16) model of monitoring becomes:

$$y(t)=\sum_{i=1}^{M}\left(\sum_{k=1}^{N} h_{ik}\tilde{\varphi}_k(t-\tau_i,\omega_i\cdot k,\psi_i)\right)+n_i(t),\quad t\in\left(0,M\cdot T\right) \quad (17)$$

Model of Additive Noise $n(t)$

In this place we shall note, that for the further analysis the aprioristic knowledge of statistical characteristics of noise $\tilde{n}(t)$ is important. The ideal situation is a knowledge of aprioristic distributions of all sections of stochastic process $\tilde{n}(t)$, but in our case would be enough to know only its first moment $E[n(t)]=\mu(t)$, as the further procedure of processing assumes summation of record result of fragments of an experiment, i.e. reception of an estimation $\hat{E}[n(t)]$. This knowledge is still important and that as a result of carrying out of experiment and at data processing supervision there would be no accumulation of a regular error. The aprioristic knowledge of $\mu(t)$ will allow to carry out preliminary such procedure as $y(t)-\mu(t)$ and by that to minimize a regular error at an estimation of a signal, i.e. to take under consideration such process $n(t)$ for which $\mu(t)=0$. In this case procedure of summation of experiments set would state an estimation of value μ in each point *t* asymptotically, by quantity of the experiments, coming nearer to zero, i.e.

$$E[n(t)]=\mu(t) \quad (18)$$

Model of Data Processing

The following procedure of the observant data processing, which is based on piling signals up experiment of the environment response, is chosen.

$$\hat{E}[s(t)+n(t)]=\frac{1}{I}\sum_{i=1}^{M} y_i\left(t-(i-1)\cdot T\right)=\frac{1}{I}\sum_{i=1}^{I} s\left(t-(i-1)\cdot T,\vec{h}_i\right)+\frac{1}{I}\sum_{i=1}^{I} n\left(t-(i-1)\cdot T\right) \quad (19)$$

Here $\hat{E}[s(t)+n(t)]$ is an estimation of a population mean of the environment response and an additive noise, and $I=M\cdot T$ is the time of monitoring.

Density of distribution of the random parameters which are included in model (1) are necessary for definition of a population mean (19) us. Reception of estimations of aprioristic distributions of a vector of parameters $\vec{h}$ does not represent work since the source of probing signals always can be tested a priori, before carrying out of experiment, and the necessary statistics of the non-stable parameters determining a signal, thus can be received a priori.

We shall consider, that the aprioristic statistics gives the good consent with some density $dP\left(\vec{h}\right)$.

Example

With the purpose to get the monument spectral characteristics, logarithmic decrement of the oscillations of the object and to analyses of damping ability of the system, which was realized at the monument for oscillation reduction, the site tests were carried out. For registration of fluctuations three-directional geophone with gauges located on three mutually perpendicular axes was used. The special characteristics of gauges represent one-modal curve with the extreme point in f=l Hz. Geophones were placed at a horizontal surface, on the level of 42 meters. They served as a part of interface of the monitoring registration and processing automated system. This system allows correcting the spectral characteristic up to uniform in the chosen range of frequencies. The first part of experiment consisted in registration of monument reaction on a natural background as an input signal. This signal represents a superposition of the large number of the external factors from natural microseism noise and men made one up to signals from ground transport. The important moment is that the total spectrum of this signals is much wider then the response spectrum of the monument. For the monument it was obtained three modes on frequencies 0.48 Hz, 0.93 Hz and 1.47 Hz with corresponding amplitudes 1.0, 0.07 and 0.12. The frequency of 1.47 Hz with rather intensive amplitudes hypothetically is devoted to the mode of the top sculpture, the framework of which is less rigid then the framework of the self column. The second part of experiment was consisted in to get a logarithmic decrement of oscillation of the monument on the basic resonant frequency. For this purpose was used a damp of pendulum type. By compulsory swinging of this pendulum the monument was coupled in fluctuations and then the fluctuations faded by a natural way. The average value estimation of the logarithmic decrement of the oscillations was equaled 0.055. This figure shows that the metal column with granite shell has rather low capacity to dampen fluctuations. The damper, when it was put in operation during the tests, has increased the ratio of the logarithmic decrement of the oscillations up to the level was equaled 0.18-0.25. The damper construction gives the possibility to obtain greater ratio of logarithmic decrement of the oscillations via increasing of the friction coefficient the energy absorber. It's necessary to note that the spectrum of a structure is its steady characteristic. This function varies with change of mechanical parameters of a structure and can be used for detection of "age" changes of a structure while in exploitation. It's possible to consider that the fixed spectral monument characteristics further can be used as reference for detection of a beginning of the moment "age" changes during a structure-monitoring period.

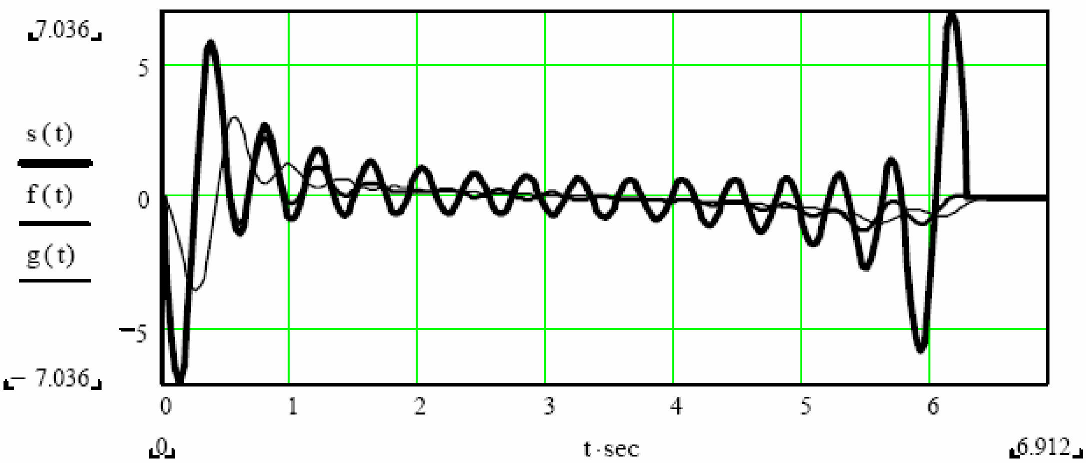

Figure 1

At the figure 1 here are three curves: the first one, which is marked as $s(t)$, is model of sounding signal. The second one ($f(t)$) is misshaped signal by random frequency fluctuation, the third one ($g(t)$) is misshaped signal by random frequency fluctuation and start time fluctuation. Having fulfilled procedure of signal reconstruction one get the curve shape very closed to be the shape of origin one $s(t)$.

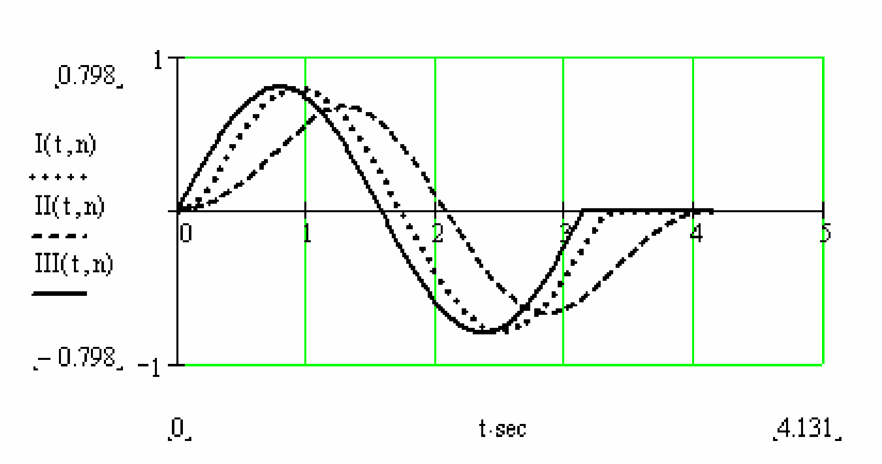

Figure 2

In figure 2 for a case of a signal (13) three curves showing the basic frequency after accumulation procedure are shown. Frequency and interval are functionally connected in the process of fluctuation. Curve I (n) - for a case when fluctuations are symmetric concerning frequency ω_0, II (n) - for a case when fluctuations are not symmetric concerning frequency ω_0 (entropy is equal 2,301 in both cases), III (n) - actually a harmonic without distortions

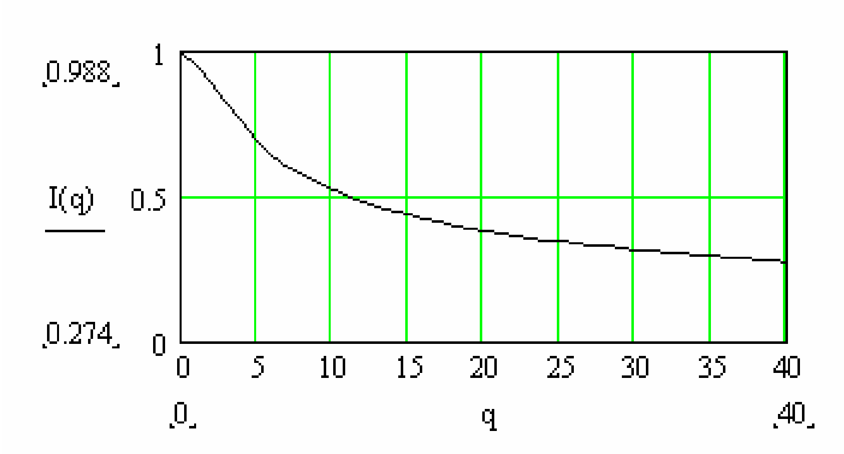

Figure 3

In figure 3 the dependence of a norm of basic function attenuation as a function of number of a harmonic after procedure of accumulation is submitted (in case of the only start moment fluctuations). On an axis of ordinates the amplitude in relative units is shown.

Conclusion

One can find proposed and analyzed original math model of an active monitoring system for manmade and natural objects. The system was used for analyzing of real object characteristics physically. The measurement is based on piling environment response up as a reaction for flow of stochastic weak signals. The response signal correction is used premature probability of instability parameters of testing signals set generator. It is shown that the main source of instability testing signals is not only the time of signal departure but frequency and phase instability as well. For elimination of defects the decision-making procedure is proposed.

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BUILDING DATA WAREHOUSES USING NUMBERED INFORMATION SPACES

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Abstract: An approach for organizing the information in the data warehouses is presented in the paper. The possibilities of the numbered information spaces for building data warehouses are discussed. An application is outlined in the paper.

Keywords: Data Warehouses, Operational Data Stores, Numbered Information Spaces

ACM Classification Keywords: E.1 Data structures, E.2 Data storage representations

Introduction

The origin of the Data Warehouses (DW) can be traced to studies at MIT in the 1970s which were targeted at developing an optimal technical architecture [Haisten, 2003]. The initial conception of DW had been proposed by the specialists of IBM using the concept “information warehouses” and its goal was to ensure the access to data stored in no relational systems. In 1988, Barry Devlin and Paul Murphy of IBM Ireland tackled the problem of enterprise integration head-on. They used the term "business data warehouse" and defined it as: “a repository of all required business information” or “the single logical storehouse of all the information used to report on the business” [Devlin and Murphy, 1988]. At present, the conception of “data warehouse” becomes popular mainly due to activity of Bill Inmon. In 1991, he published his first book on data warehousing.