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Algorithm and Software for Landslide Slopes Stability Estimation with Online Very Low Frequency Monitoring

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Abstract. In addition to preliminary surveying, landslide slopes stability estimation problems require online real-time monitoring alerting about potential emergencies. Very low frequency monitoring data provided by geodynamic processes automated control system provides a solution to that problem. Authors describe the software and algorithms implemented for that system, make conclusions on the efficiency of applied solutions and propose options for the further development of online very low frequency monitoring system.

1. Introduction

Landslide stability estimation is heavily used in engineering and geodetic surveying. Such methods are mostly based on the quantitative slope stability estimations prior to design and construction works at a respective site [1]. However, lately a new research direction is developing rapidly, focusing on online monitoring, estimation and prediction of soil engineering stability. In such approach Earth's natural pulsed electromagnetic field (ENPEMF) recorded data could be an essential information source [2–4].

To measure those fields Multichannel geophysical recorders "MGR-01" were designed and built at IMCES SB RAS [5]. "MGR-01" records pulse signals by electric and magnetic components of the field, and for the magnetic component measurements are performed in a narrow band on very low frequencies (VLF) using two mutually perpendicular directions for signal reception. "MGR-01" recorders are certified (certificate No 24181), registered in a state registry of measurement devices and legal to use in Russian Federation. Based on those devices, fixed networks accumulating the real-time data were created [6]. In addition, two new types of device were introduced to the networks lately – MTZ recorder having three recording channel instead of two and GR recorder with a single recording channel.

To aggregate all the accumulating data and to allow various user groups to access that data, the software was developed as a part of a geodynamic processes automated control system (GPACS).

2. GPACS software general structure

The general structure of GPACS software is outlined on Figure 1.

Software was implemented on the platform of Java 2 EE + JBoss Application Server, using MySQL RDBMS as a data repository.

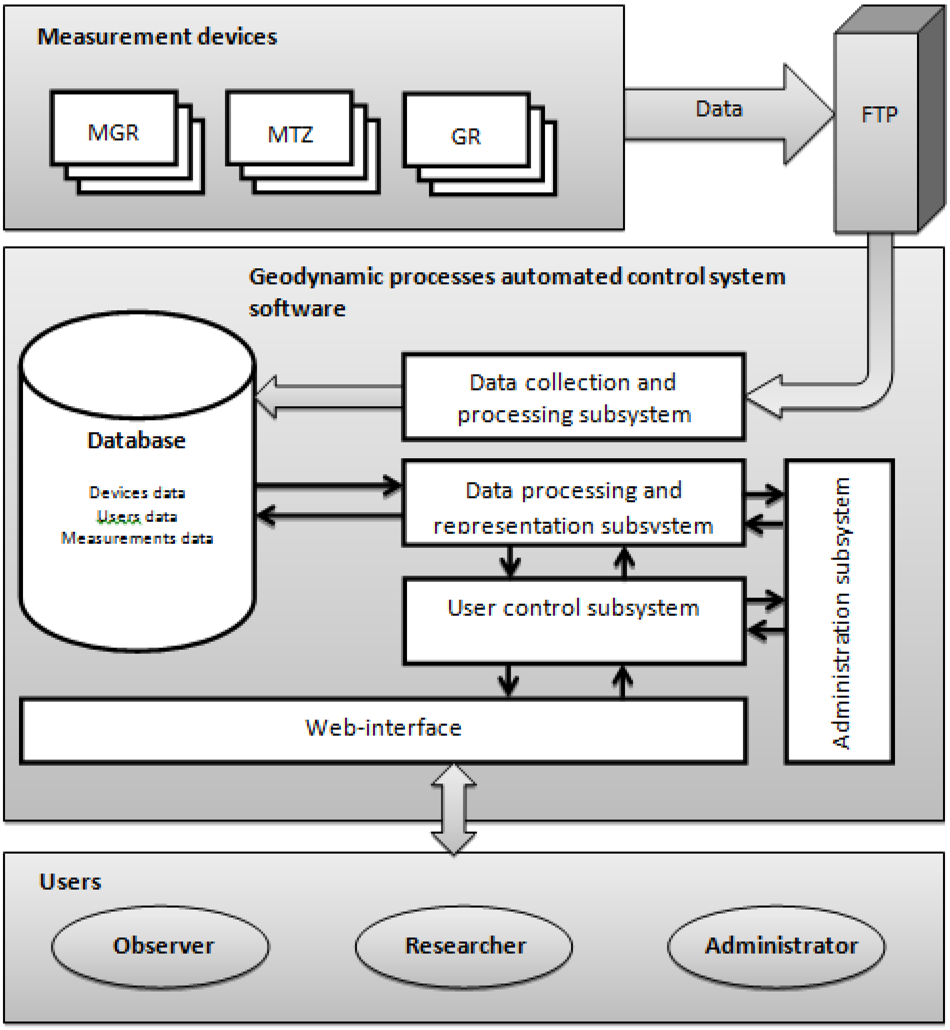

Figure 1. General structure of GPACS software.

The following core subsystems can be identified in the software:

1. Data collection and processing subsystem. This subsystem performs the input of the data coming from the devices into the database. More detailed description follows in section "Data collection from measuring devices in GAPC".
2. Administration subsystem. That functionality is designed to manage device service data, user groups and system overall settings.
3. User control subsystem. This subsystem performs access differentiation for separate user groups varying in functionality, data visibility and interface layout.
4. Data processing and representation subsystem. Major functionality part of the system, providing features to filter data for a user, processing data to detect dangerous geological processes, providing features to either review the data in web-interface or export it in user-specified format.
5. Web-interface. A thin client working in any web browser, responsible for user interaction with the system.

3. Data collection from measuring devices in GAPC

Recorders data is output in fixed data interval and accumulated on ftp server as files with the naming pattern of XXXXX_DDDDDD_TTTTTT.mgr, where XXXXXX is a recorder descriptor, DDDDD is measurement date, TTTTTT is output time. Currently recorders export their data once in four hours.

System automatically imports measurement data from ftp servers aggregating it into the database. During the import the following data operations are performed:

1. For each recorder a control channel E value is checked and the data considered invalid is excluded from the representation and analysis. That data is however stored in the database to observe a respective device statistics – if invalid data threshold is exceeded for a recorder – the hardware check is scheduled.
2. Hourly average values are calculated and stored separately in the database. While it looks like a theoretical violation of database design normal form, it still makes a practical sense, because those particular average values are heavily used in further analysis and it is more efficient to duplicate information rather than sacrifice computational efficiency later on.

4. Online monitoring software

One of the key requirements for the system design was a simple data access in any circumstances. Therefore, it was a logical choice to use a thin client architecture, where any workstation with an internet connection and web browser could be used to access the system. Software allows to work via web-interface with either a single station (recorder) or a set of stations. The following functionality is available:

1. Output measurement data for a selected period of time. Both raw and hourly average data can be viewed.
2. Export measurement data to tab-separated values file for the further analysis in any third-party software.
3. Review measurement data plots for a station or a group of stations – either raw or hourly average.
4. Review the plots composed by the stability estimation algorithm. Described in more detail in the section “landslide slope stability estimation algorithm”.

In addition, there is a number of service features in the system, including administrative interface to set up graphic representation, user groups, station groups, ability to review the device statistics and so forth.

Overall functionality of the system makes it useful for the following three user categories:

1. Observer, performing online monitoring of landslide slope stability. With the help of the algorithm he can make a decision on the necessity of on the ground inspection.
2. Researcher, analyzing temporal sequences of accumulated data to suggest new decision strategies and distinguish possible underlying tendencies.
3. Devices network administrator, performing maintenance control of the recorders and managing the system usability.

5. Landslide slope stability estimation algorithm

Landslide slope stability estimation algorithm based on ENPEMF uses two criteria. The first criterion indicates difference in the intensity of the measurements between a set of recorders located at the stress-strained rocks state control sites and a reference recorder. Reference recorder is placed no farther than 25 km (VLF wave length) from control recorders at a location, which is not a subject to geodynamic processes. Another criterion estimates a degree of similarity in different recorders readings. Excess in the intensity of ENPEMF pulse flow in each measurement point relative to reference station is calculated using Equations:

$$K_{(N-S)} = \frac{(N1_{T(i)} - N1_{T(r)})}{N1_{T(r)}}, \qquad K_{(W-E)} = \frac{(N2_{T(i)} - N2_{T(r)})}{N2_{T(r)}},$$

where $N1_{T(i)}$ is ENEMPF pulse flow intensity in north-south direction on i-th measurement station; $N2_{T(i)}$ is ENEMPF pulse flow intensity in west-east direction on i-th measurement station; $N1_{T(r)}$, $N2_{T(r)}$ is ENEMPF pulse flow intensity in north-south and west-east direction on reference measurement station.

If coefficients *K*<0, then we consider that the mechanical compression strains emerge in a respective direction, either north-south or west-east. If *K*>*0*, tension strains emerge. The greater the value of *K*, the higher are strains. That parameter is one of the most essential criteria for ground conditions geodynamical estimation.

The second parameter for stress-strained ground state is the estimation of correlation between the forms of intraday ENPEMF intensity variations of reference station and *i*-th control station. To calculate correlation coefficient of two samples Spearman's Equation is used [7]:

$$r = 1 - \frac{6}{n^3 - n} \sum_{i=1}^{n} (x_i - y_i)^2 ,$$

where *n* is sample size (number of measurements, used for the calculation); x_i is first sample i-th element's rank in that sample (e. g. sample is {5, 8, 4, 6}, then $x_1 = 2$, $x_2 = 4$, $x_3 = 1$, $x_4 = 3$); y_i is second sample *i*-th element's rank in that sample.

Further on, integrated coefficient for landslide slope geodynamical state stability is calculated using the Equation:

$$R_a = \frac{k + (1 - r)}{2} ,$$

where R_a is aggregated criteria for the residual stability of a particular location, which value is determined empirically.

It should be considered dangerous for an industrial site if integrated coefficient exceeds 150% for three days or more.

Example of integrated coefficient plot can be seen in the Figure 2.

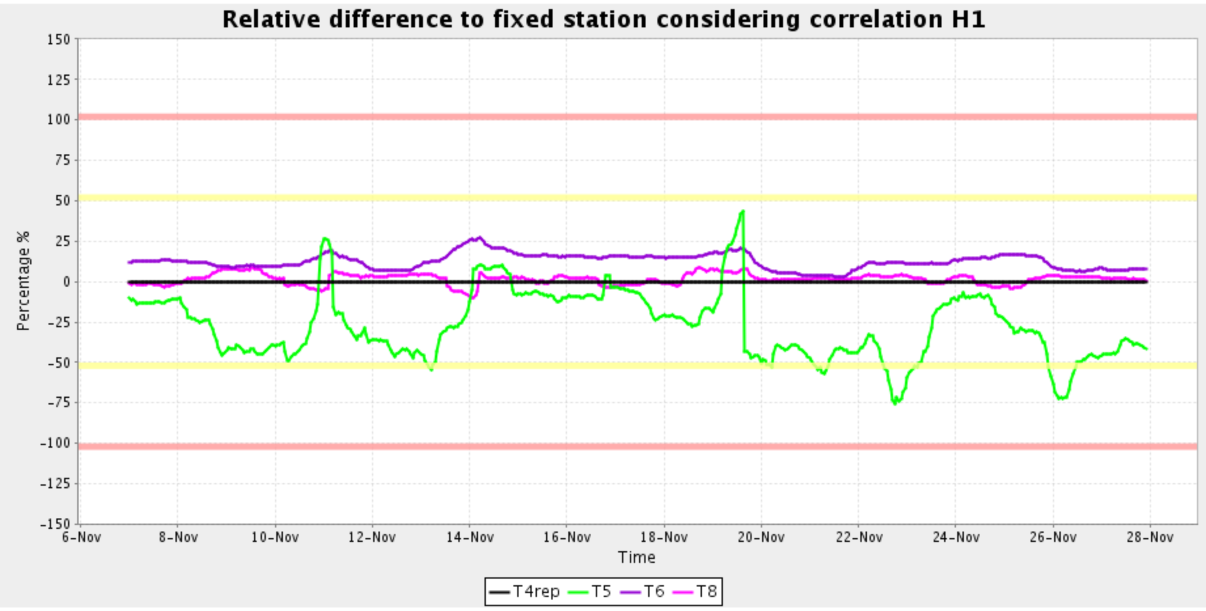

Figure 2. An example of integrated coefficient used for a set of four stations. Reference station is T10.

6. Summary

Suggested application for ENPEMF signal processing of the spatially distributed network of stations provided accurate, reproducible results, reflecting geodynamical processes activity with a very high confidence. The system allows to determine landslide hyperactivity and hypoactivity zones, tension and compression strains zones, spatial orientation of stress for a slope structure in real-time.

During the system operating time the anomalies in ENPEMF pulse flow were observed over 10 times on different section of the slope. Anomalies manifested as distortions in diurnal trajectory of

ENPEMF intensity for several days. In those days there also was a substantial difference in the reading of the stations located on different sections of the slope.

As a further development of this work it seems logical to enhance the system autonomy and to shift the focus in landslide danger decision making process from a human operator to a fully automated algorithm. That would inevitably require a higher quality of critical situation automated recognition. Random processes change point detection algorithms looks a promising direction of development [8]. Within that approach it is proved possible to construct a procedure automatically detecting a change in the mean or variance of a random process and moreover determine the parameters of such procedure providing optimal ratio between a delay in change detection and a number of false alarms.

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