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Automation of Surveying Solutions in the Mining and Geological Information System at *Uralkali* PJSC

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Автоматизация решения маркшейдерских задач в рамках создания горно-геологической информационной системы ПАО «Уралкалий»

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potash salt deposit, mining and geological information system, mine surveying, software module, digital mining plans, database management system.

The work deals with automating surveying solutions for the specialists of Uralkali, PJSC. The developed software modules are fully integrated into the corporate mining and geological information system of Uralkali, PJSC, and are grouped into specialized software systems - automated workstations. These complexes are installed at the workplaces of various mining specialists, from the heads of technical departments to employees of departments at the mines. In total, 21 software systems were developed, of which three workstations were created for the specialists of the company's mine surveying service. For the Mine Surveying Departments at the mines, an automated workstation *Local mine surveyor* was developed and put into commercial operation, for the Department of Capital Surveying and Geodetic Works, an automated workstation *Capital mine surveying* was developed , for employees of the Department of the Chief Mine Surveyor of Uralkali, PJSC, we used an automated workstation *Chief surveyor*.
The software modules that are part of the automated workstations of the specialists of the mine surveying service allow solving a wide range of engineering problems according to the requirements of the current regulatory documents. Among them, one can single out such tasks as: processing the results of instrumental survey of underground and surface objects and, on its basis, replenishment of mining and graphic documentation in digital form (2D and 3D); mining planning and design; preparation, editing and printing of standard technical documentation (payroll, tables, reports and graphics); solving issues of safe mining; analysis of the implementation of planned and design indicators of the mining enterprise, etc.

Ключевые слова:
месторождение калийных солей, горно-геологическая информационная система, маркшейдерские работы, программный модуль, цифровые планы горных работ, система управления базами данных.

Приводятся результаты работ по автоматизации решения инженерных задач, стоящих перед специалистами маркшейдерских служб рудников ПАО «Уралкалий». Разработанные программные модули полностью интегрированы в корпоративную горно-геологическую информационную систему ПАО «Уралкалий» и сгруппированы в специализированные программные комплексы – автоматизированные рабочие места. Данные комплексы установлены на рабочие места различных специалистов горного производства, начиная от руководителей технических подразделений и кончая сотрудниками отделов на рудниках. В общем разработан 21 программный комплекс, из них три автоматизированных рабочих места созданы для специалистов маркшейдерской службы компании. Для маркшейдерских отделов на рудниках разработан и внедрен в промышленную эксплуатацию автоматизированное рабочее место «Участковый маркшейдер», для отдела капитальных маркшейдерско-геодезических работ – автоматизированное рабочее место «Капитальные маркшейдерские работы», для сотрудников отдела главного маркшейдера ПАО «Уралкалий» – автоматизированное рабочее место «Главный маркшейдер».
Программные модули, входящие в состав автоматизированных рабочих мест специалистов маркшейдерской службы, позволяют в автоматизированном режиме решать широкий круг инженерных задач, обусловленных требованиями действующих нормативных документов. Среди них можно выделить такие задачи, как: обработка результатов инструментальной съемки подземных и поверхностных объектов и на ее основе пополнение горно-графической документации в цифровом виде (2D и 3D); планирование и проектирование горных работ; составление, редактирование и печать типовой технической документации (расчетные ведомости, таблицы, отчеты и графика); решение вопросов безопасного ведения горных работ; анализ выполнения плановых и проектных показателей работы горного предприятия и др.

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Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
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Introduction

Mine surveying services at mining enterprises process large volumes of information and produce a lot of computational and graphic reports on its basis, thus it has become of increasing relevance to solve the problem of automating surveying solutions.

Requirements for the functional composition of software systems follow from the main tasks of the mine surveying service at mining enterprises [1]. In general, these tasks can be briefly defined as a complex of observations, measurements, calculations and documentation maintenance for obtaining surveying and other technical information. Therefore, the main goal of software package development is to automate the field observations processing, replenish digital mining plans based on them, determine the planned and actual mining operations indicators and prepare the reporting survey documentation.

The ability to solve engineering problems facing mine surveying services specialists at mining enterprises is present in many well-known foreign multi-functional software systems, as well as in Russian and foreign specialized developments.

The first group may include such software packages as: MineScape (Mincom, Australia) [2], VULCAN (Maptec, Australia) [3], SURPAC (Software International, Australia) [4], GEMCOM (Canada) [5], DATAMINE (MIC Ltd, Great Britain) [6], Micromine (Micromine Pty Ltd, Australia) [7], etc.

Among the specialized software developments, the following can be distinguished: RiMINING (Riegl, Austria) [8], Carlson Survey (Carlson Software, USA) [9], MINEFRAME (CREDO, Russia) [10], GEOMIX™ Mine Surveying (VIOGEM, Russia) [11], SAMARA (Laboratory of Integrated Technologies, Ukraine) [12] and some others.

A large number of offered mine surveying automation software tools have a challenge of choosing a product that best meets the optimal price-to-opportunity ratio.

Experience has shown that the purchase and implementation of foreign multi-functional software packages by mining enterprises does not always justify itself. And this is due not only to their high cost, but also, above all, to the complexity of such system implementation at user workplaces. In most cases, a specialist who solves a specific list of production tasks (for example, a local mine surveyor) has no needs in the excessive functionality of such packages. And at the same time, over and over again such specialist has to solve issues that are peculiar only to a given enterprise and not provided for by such programs functionality. It is also impossible to adapt programs to the peculiarities of solving their problems independently, since the program codes of such systems are usually closed. An appeal to foreign developers or their Russian representatives with a request to adapt the program to the specific specialists problem solving peculiarities leads to serious time and money costs.

The need for a regular updating of software products, algorithms and program codes previously developed and used at mining enterprises is often associated with changes made to the current regulatory documents governing the engineering problem solving procedure faced by various services of these enterprises. Such changes can be made at different mining management levels - federal, regional, local and a specific mining enterprise.

Recently, the sanctions have restricted the purchase and further support of foreign software products, which has limited the choice of software products.

The above, as well as some other factors, are increasingly forcing large Russian mining companies to start developing specialized programs for their enterprises with the involvement of third-party specialists. In this case, the software is developed considering all the productive processes features during the specific field mining, as well as safety and corporate standard requirements.

In particular, this is the solution of the management of Uralkali PJSC after an unsuccessful attempt to implement the foreign software package MineScape in their company [2]. In 2014, the company's management decided to develop a corporate mining and geological information system (MGIS of Uralkali PJSC) on its own. To solve the problem, Perm National Research Polytechnic University (PNRPU) specialists were involved.

By the time this paper was written (early 2021), the main system elements had been developed, successfully passed the pilot operation stage and put into commercial operation at all five productive mines. In the future, it is planned to introduce the system at two more mines under construction.

Here's the information about one of this mining and geological information system constituent parts related to the engineering problem solving automation facing the mine surveying service of Uralkali PJSC.

Functionality of Software Modules for Solving Mine Surveying Tasks at the Uralkali PJSC Mines, Created before the Mining and Geological Information System Development and Implementation

The first authors' developments related to the problem solving automation facing the mine surveying services at mines declining the Verkhnekamskoye potash salt deposit date back to the early 2000s. [13–20].

The work began with the objects classifier creation for digital plans and maps of a scale range from 1:500 to 1:10,000 [13]. Then, in accordance with the classifier, digital mining plans were established for all productive formations (Vs, Vk, AB, Kr2, "Rock Salt") of all six mines that were declining the deposit at that time. Works on the digital graphics creation were carried out in accordance with the regulatory document requirements [21–28]. The digital plans and maps displayed at different scales were designed in accordance with the current standards [29–34] and saved in the detailed engineering work files. For the mining operations and earth surface digital plans graphic visualization, the GIS MapInfo was adopted, and the Oracle DBMS was used as the information repository.

Almost alongside with the digital creation of plans, we began to develop software modules that made it possible to automate the following solutions of operational tasks:

– input and processing of data obtained as an underground workings instrumental survey result;

– automatic survey objects formation and their displaying on mining operations digital plans;

– calculation of extracted mineral volumes, goaf stowing volumes and the actual losses and dilution values;

– formation and printing of graphic documentation for annual mining operation development plans and current mine surveying documentation (sections, cross-sections, profiles, operational and main scales mine surveying plans).

The software modules created during this period were in commercial operation at the workplaces of mine surveying specialists until June 2014.

The Results of Work on the Automation of the Problem Solving Facing the Uralkali PJSC Mine Surveying Service, which was Carried out within the GGIS Development

In 2014, as part of the work on the GGIS development by Uralkali PJSC, the mine surveying tasks list, the solution of which must be carried out using automation tools, was significantly expanded. As a result, three automated workstations (AWS) were formed: "District mine surveyor" AWS, "Capital mine surveying" AWP, "Chief mine surveyor" AWP. Each software package includes modules that allow solving specific operation tasks facing each of the mine surveying service employees at Uralkali PJSC.

The software package with the conditional name “District mine surveyor” AWP was developed for mine surveying departments specialists at mines and includes 23 software modules, which were developed taking into account the problem solving peculiarities facing the mine surveying departments specialists at each mine. The software package with the conditional name "Capital mine surveying" AWP was developed for the capital mine surveying and geodetic department specialists and includes 10 software modules. The software complex with the conditional name "Chief Mine Surveyor" AWP was developed for the Chief Mine Surveyor Department specialists at Uralkali PJSC and includes 8 software modules. For example, the figure shows the software loading module view included in the "Capital mine surveying" AWS, and the table contains a main tasks list solved by the mine surveying service specialists at the considered AWPs.

More details about the functionality of individual software modules can be found in the previous authors' publications [35–41].

Main Technical Architecture Elements for the GGIS of Uralkali PJSC

The basis of the developed mining and geological information system is a single database, which until 2021 was Oracle 12c DBMS, and since 2021 - Postgres DBMS. Database information is stored in 420 interconnected tables and entered into them by means of specially developed software modules. Multiuser access is provided to graphic and attributive information stored in the DBMS.

The software modules are developed both for solving engineering problems facing the various mining enterprises services, and for entering archived data on mine workings. As already noted, software modules are combined into software packages, which have received the conditional automated workstations name (AWPs). The modular structure of software packages allows you to form a workplace with functional capabilities requested by each user of various departments at mining enterprises (mine surveying and geological services, mining and geomechanical departments, environmental monitoring services).

The software work is managed by Windows OS not lower than version 7 using the TCP/IP protocol and on the basis of "client-server" architecture.

Within the developed system, mechanisms for software modules automatic update at user workstations, in case of changes in the existing softwares functionality by the developer, for administration of access rights to the information in the DBMS tables and for recovering erroneously deleted data are implemented.

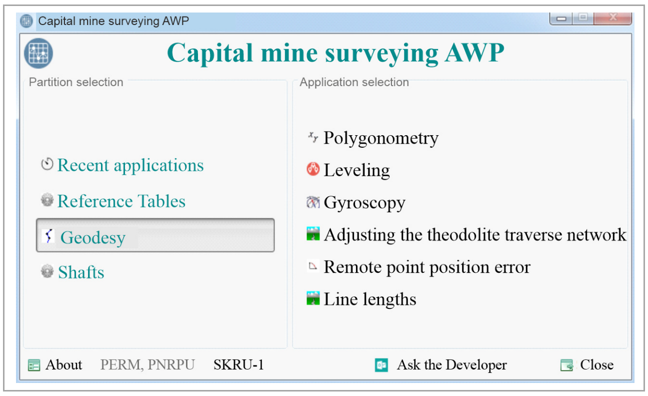

Fig. Loading module of softwares included in "Capital mine surveying" AWS

Working with graphic information is carried out in accordance with the approved "Classifier of objects for digital plans and maps of Uralkali PJSC" requirements, and its visualization is possible in the following GISs: QGIS, MapInfo, ArcGIS, AutoCad Map 3D.

Formation, execution and printing of standard reporting documents are semi-intelligent, taking into account the current federal, regional and corporate regulation requirements [1, 42–45].

Organizing the System Introduction into the Pilot and Commercial Operations

The experience of developing the GGIS of Uralkali PJSC has shown that the most labor-intensive are activities of system elements implementation into the user workplaces at the pilot scale and commercial operation stages. Without going into the analysis of reasons for this, within this work, we would like to highlight those activities, the implementation of which made it possible to solve the tasks at these stages:

1. Creation of a group for the system implementation into the pilot scale and commercial operations. The group includes full-time specialists from all divisions of Uralkali PJSC, where the GGIS elements are installed. The responsibilities of this group specialists include: information, organizational, methodological and legal support of the software developer (PNRPU); system elements testing; users consultation at workplaces; acceptance of works performed by the contractor.

2. Technical facilities uninterrupted operation provision by the Uralkali PJSC IT services (servers, user PCs, network hardware, regulate access rights to the software modules functionality , data safety, etc.).

3. Training of implementation group employees and users at workplaces in operation of software modules provided by the contractor's specialists.

4. Development by the contractor (PNRPU) and transfer to the customer (Uralkali PJSC) of the necessary accompanying documentation for GGIS (administration manual; regulations and step-by-step instructions for users; database model; instructions for backing up and restoring data; installation instructions; documentation for the platform and components of applied solutions, etc.).

5. Execution of works by the contractor to support and develop the system at the pilot scale operation stages, and after the software packages introduction into commercial operation at the stabilization and technical support stages.

Main tasks solved by the software modules included in the Uralkali PJSC mine surveying service software packages

Task group	List of tasks to be solved
	AWP "Local surveyor" (contains 23 software modules)
Review and input of raw data	1. Initial workplace settings: name description for the mine, productive formations, panels, blocks; forming a mine surveying department employees list and their "binding" to the serviced mining area
	2. Adding, editing, deleting information on the location, purpose and type of mine workings. Automatic workings' name generation according to the standard fields set in the table of its characteristics
	3. Reviewing information on planned and actual production volumes for the selected continuous heading machine
	4. Reviewing and analyzing the values of vertical and horizontal ground surface displacements and deformations over the mining areas
	5. Providing storage, search and review of technical and regulatory documentation developed by specialists of Uralkali PJSC, subcontractors and government regulatory organizations in a structured file data archive
	6. Reviewing information on existing points of the surveying reference network (SRN) on the surface and in mine workings
	7. Reviewing materials on calculating the size of pillars for protected facilities and mitigation zones, etc.
Design/ planning	1. Formation of mine workings cross-sectional design sections depending on the continuous heading machine, mined formation capacity, number and cutter-loading passes spatial arrangement
	2. Planned mining volumes distribution by continuous heading machines, work types, mining areas, as well as mineral types (carnallite, sylvinite) per month
	3. Determination of the axes of mine workings within the boundaries of planned mining zones
	4. Calculation of planned standards for losses and mineral dilution for each extraction unit
	5. Determination of stowing wells optimal position and bridges for each workings being poured or working blocks. Calculation of planned backfill volumes for mine workings, depending on the each working design backfill factor, block, panel, formation, mine, etc.
Surveying measurements processing/ Results analysis	1. Determination of the continuous heading machine executive body shape and cross-sectional area according to the surveying measurements results. Calculation of the chipped ore mass average specific losses for the selected shearer continuous heading machine
	2. Processing the instrumental measurements results to determine the coordinates and elevations of underground survey network (SN) points
	3. Processing the mine workings surveying measurements results. Mined rock mass volumes calculation. Annual mining development plan (AMDP) parameters implementation analysis
	4. Calculation of the minerals operational losses for each extraction unit. Excess losses analysis
	5. Processing the surveying measurements to determine the actual backfill volumes in the worked-out area, depending on its type and purposes. Backfill plan execution analysis
	6. Determination of finished product volumes in warehouses and enclosing rock volumes in dumps
	7. Collecting and displaying the information statistical analysis results on mine workings stored in the DBMS according to generated user queries
	8. Solving production tasks on the mine workings 3D models basis, etc.
Working with digital graphics	1. Binding to a graphic display of workings on an attributive information digital plan from the DBMS
	2. Drawing and viewing on a mining operations and sections digital plan: - boundaries of design and planned mining zones for the selected mining operations date; - mine workings positions - mining areas of each continuous heading machine; - mine workings backfill areas; - theodolite and leveling traverse points and cross-sections positions ; - boundaries of pillars, mitigation zones, hazardous zones, etc.
	3. Building and analysing mine workings 3D models
	4. Building and printing the thematic maps displaying raster and isolinear surfaces according to the selected parameters of vertical and horizontal deformations and ground surface displacements . Plotting and printing the appropriate graphs
	5. Forming, displaying and printing the standard mine surveying plates of working (Scale 1:500 and 1:1,000) and basic (Scale 1:2,000) graphic documentation in accordance with the current GOSTs requirements for mining graphic documentation design
Reports	Reporting documentation preparation: to the AMDP; on accounting and movement of stocks by extraction units; by the volume of voids and fillings; calculation notes and outlines based on the results of processing instrumental observations in mine workings; based on the results of determining the planned and actual mineral losses, etc.
	"Capital mine surveying" AWS (contains 10 software modules)
Reviewing and entering raw data	1. Review and analysis of the project for capital mine surveying implementation
	2. Review and analysis of up-to-date information on the shaft reinforcement and support status. Obtaining initial data for conducting mine surveying in the shaft and when checking the surface shaft unit objects state
	3. Data conversion on benchmarks, surveying points and profile lines stored in files of various formats into DBMS tables, etc.
Surveying measurements processing/ Results analysis	1. Surveying measurements processing in a vertical mine shaft: when profiling conductors; when profiling the vertical shaft walls; when determining safety clearances in the shaft; when measuring the conductors dimensions. Data analysis (color indication)
	2. Surveying measurements processing for geometrical elements of the mine lift surface unit: pile driver, sheave wheels platform, sheaves, winding machine ropes, winding machine, etc. Data analysis (color indication)
	3. Processing the results of instrumental measurements in theodolite and leveling traverses passed by the accuracy of survey reference network (SRN) on the ground surface and in the mine. Adjusting the theodolite traverse system (method by Prof. V.V. Popov), including taking into account th individual sides gyroscopic orientation data
	4. Analysis of the underground survey reference network state by calculating the position error of the polygonometry point farthest from the shaft (three methods)
	5. Entering and processing the instrumental observation results on the of profile lines benchmarks to calculate the vertical and horizontal displacements and deformations of the undermined ground surface. Analysis of results obtained
	6. Determining the degree of mining operation effects on the protected surface objects. Calculation of the undermined objects permissible and maximum deformations and their comparison with the actual deformations (color indication), etc.
Drawing up the calculation and graphic reporting documentation	1. Forming, editing and printing the reporting documentation based on the results of: surveying measurements in a vertical shaft; surveying measurements of the mine shaft lifting unit objects geometric elements; instrumental measurements in theodolite and leveling traverses, including along profile lines on the ground surface and in the mine, etc.
	2. Drawing up and printing the calculation and graphic documentation for the project of underground SRN development. Materials for adjusting the networks of leveling and theodolite traverses
	3. Replenishment of the digital layout plan of: profile lines benchmarks and cross-sections; theodolite and leveling traverses passed by the accuracy of SRN; gyroscopic oriented cross-sections; undermined objects with critical deformations values (color indication), etc.
	4. Plotting the graphs according to the calculated undermined ground surface parameters of displacements and deformations
	"Chief mine surveyor" AWP (contains 8 software modules)
Data viewing	1. Possibility to view the necessary information from the file archive (Certificates in the form 70-TP and 5-GR for all years; current and archival shaft inspection reports; a cascade of documents coming out of the surveying departments for a selected period of time, etc.)
	2. Viewing information from the database on pre-formed queries: - for wells: primary and revision coordinates, references to the control survey reports, etc.; - a list of instruments and tools available in the surveying departments, their characteristics, approximate withdrawal date, data on analytical tests; - design and planned indicators for the mining operations development in productive formations for the current and next year; - viewing the combined plans of underground mining with the surface; - viewing the topographic plans of industrial mine management sites; - viewing the plans with the actual position of mine workings for each productive formation at the requested scale; - viewing the general mine losses book; - viewing the graphs of subsidence and subsidence rates, compiled from the instrumental observations results using the benchmarks of profile lines on the ground surface; - viewing the thematic maps of subsidence and subsidence rates of the ground surface (isolines); - viewing the materials on the design of land and mining allotments, etc.
	3. Viewing information from the repository of scientific and engineering data (SED) library
Control/ Analysis	1. Daily control over the mining plan execution by analyzing the data entered through AWPs
	2. Mining operations safety analysis in potentially hazardous areas based on the following data: mining parameters; backfill terms and parameters; actual subsidence rates of the ground surface; conclusions of scientific and design organizations. Drawing up a thematic map of potentially hazardous areas and linking attributive information to them
	3. Determination of waterproof strata risks (WPS) underworking (including in the mitigation zones) based on a comparison of calculated and permissible the WPS rock layers deflections . Drawing up a thematic mine field map with the hazard degrees of WPS underworking
	4. Analysis of the surface objects state falling into the zone of mining operations influence based on a comparison of actual and permissible deformations for a specific object (color indication of objects on digital layers, when actual deformations excess permissible ones). Binding of attributive information to the objects graphical display (object data sheet, the results of instrumental observations for the object state, scans of available documents, etc.)
	5. Sampling schedule management to determine physical and mechanical properties of rocks (in accordance with the AMDP)
	6. Comparative analysis of operational, planned and design mineral losses for each extraction unit for all mines of PJSC. In the presence of excess losses - viewing reports on the reasons for their occurrence
	7. Monitoring compliance with the grading schedule for all wells (color indication)
	8. Monitoring compliance with the observation schedule for profile lines on the ground surface (color indication)
	9. Control of the timely information entry on the results of objects on the ground surface mine surveying and mine workings into the DBMS tables of GGIS of Uralkali PJSC (color indication by type of mine surveying)
	10. Analysis of the SRN networks timely development when approaching mine workings to the hazardous area boundaries (color indication)
	11. Analysis of up-to-date data on the stocks volumes prepared and ready for extraction based on a comparison of actual data and the plan
Reports	Forming and printing the summarized reports for Uralkali PJSC for a specified interval: by mineral extraction volumes and losses; by volumes of voids and goaf stowing; by volume of wastes on the surface (salt tailings piles, sludge dumps) and by residues of minerals in warehouses; to assess the degree of harmful mining operations impact on protected surface objects, etc.

Conclusions

Despite the short period of GGIS elements used in the mine surveying service of Uralkali PJSC (1.5 years), the following main advantages of their implementation are already becoming obvious:

– increased safety of mining operations by improving the mining operations design and planning quality, as well as eliminating the errors in processing the instrumental mine surveying results of objects on the ground surface and in rock mass;

– increased labor productivity of specialists from the mining enterprises mine surveying service by saving operation time when solving current surveying tasks in an automated way;

– increased operability, improved quality and reliability in the reporting survey documentation preparation (graphic, text, calculating, etc.) for both, internal purposes and state organizations (Federal Environmental, Industrial and Nuclear Supervision Service [ROSTEKHNADZOR], Federal Subsoil Resources Management Agency [ROSNEDRA], Federal Supervisory Natural Resources Management Service [ROSPRIRODNADZOR], etc.)

– increased specialist knowledge level from the mining enterprises mine surveying service due to their mastery of new (digital) technologies.

Keeping the system up-to-date also becomes obvious. The main reasons for this are: changes in the existing regulations governing the mineral resources development; changes in methods for calculating various indicators of mining operations; changes in the requirements for reporting documents by state regulators; renewal of the fleet of mechanical means used in the mineral extraction, as well as surveying instruments and tools, etc. Since the software codes are open for the job requestor, the PJSC Uralkali's IT services specialists will be able to cope with some of the updating tasks the software on their own. This will significantly reduce the enterprise's costs for system support and its further development.

In conclusion, it should be noted that in 2019 the corporate GGIS developed and implemented in the divisions of Uralkali PJSC, according to the professional community of digital transformation leaders GlobalCIO|DigitalExperts, was recognized as the best IT project in Russia and CIS (category - Best Industry Solution, nomination - Metallurgy and Continuous Production) [46].

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