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TELECOMMUNICATION SOLUTIONS FOR HIGH-PRECISION SATELLITE POSITIONING AT KACHARSK QUARRY

With the increasing need for digitalization in mining production, the relevance of applying modern geodesy and surveying technologies, particularly using digital communication systems and satellite navigation, has significantly increased. Scientific and technical progress has enabled the development and implementation of high-precision measurement technologies that significantly surpass traditional methods in performance and accuracy. A differential correction base station utilizing GNSS (Global Navigation Satellite Systems) data for measurements is created as a part of the geodetic work automation at Kacharsk deposit.

This article presents the development of a software and a technical facility for a high-precision satellite positioning system, which has successfully passed all testing stages and has been implemented in industrial operation. This integrated system allows measurement tasks to be performed in real-time and post-processing modes, taking into account the complex conditions of signal transmission at the depths of quarries and beyond the dumps. The work was conducted by the D.A. Kunayev Mining Institute in collaboration with the Institute of Space Technique and Technology. The project co-financing by a private partner JSC "SSGPO".

The development includes creating a differential correction center, which facilitates the transmission of correction information and differential corrections to mobile devices at the site. This provides the increased measurement accuracy and optimized production management processes in the constantly changing geometry of the quarry. A software-based mathematical algorithm for processing and analyzing satellite data has been developed within the project, significantly enhancing the efficiency of geodetic measurements.

The implementation of satellite technologies not only improves the accuracy and efficiency of geodetic works but also promotes the digital transformation of the entire production process at Kacharsk deposit. Such developments are a key element in the strategy of creating an "intelligent mine", where all processes are maximally automated and optimized to ensure safety, efficiency and sustainability of production.

In the context of sustainable development, the adoption of these technologies also contributes to minimizing the environmental impact of mineral extraction through precise positioning and planning of mining, leading to reduced waste and optimized resource usage. Financing and support for such projects highlight the importance of integrating science and technology into the sustainable development of the industry.

Keywords: *mining production digitalization, geodetic measurements, high-precision satellite positioning, GNSS (Global Navigation Satellite Systems), DCBS (Differential Correction Base Station), telecommunication solutions, UHF signals (ultra-high frequency), repeater*

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Introduction

In the context of the active digitalization and automation of the mining industry, the scientific and technical community aims to create standardized and efficient systems for managing technological processes [1]. A particularly important aspect is the development of high-precision satellite positioning systems that enable comprehensive automation of open-pit mining operations. This paper describes the experience of applying modern differential correction technologies of GNSS signals at the Kacharsk deposit—one of the largest quarries in Kazakhstan, located 55 km from the city of Kostanay.

The depth of this quarry reaches 500 m with a planned deepening to 764 m, creating challenging conditions for conducting satellite navigation measurements due to the terrain and rock characteristics. The volume of mined rock mass is expected to exceed 11 billion m^3, with four spoil heaps already constructed. Under such conditions, traditional geodesy methods do not provide the required accuracy and speed. This highlights the need for differential correction using base stations for accurate determination of coordinates for both mobile and static objects at the site. Generally, the paper addresses the problem of signal transmission to the bottom of the quarry and beyond the spoil heaps, which has been successfully resolved during the testing of the developed system.

The study relies on the review of scientific works in the fields of geodesy, satellite navigation and automation of mining operations. Particular attention is paid to the use of differential correction in challenging conditions, such as great depths and complex terrain, where standard navigation methods are ineffective. The key sources include research articles [2–5] and other studies discussing the multi-frequency use of GNSS systems, including GPS, GLONASS, Galileo and BeiDou, to improve positioning accuracy. These works emphasize the importance of using modern technologies in geodetic research and propose methods for enhancing positioning systems in challenging environments. Of equal significance are the works [6–9] which propose methods for calculating and using differential corrections, significantly improving positioning accuracy.

Main objective

The primary goal of the developed facility is the determination of geodetic coordinates using modern satellite navigation technologies in real-time and post-processing modes. During the testing process, the issue of signal transmission to the bottom of the quarry and beyond the spoil heaps was resolved. The main research methods are based on the technology of differential correction of signals from the Global Navigation Satellite System (GNSS).

Methodology

The base station consists of a combination of a GNSS receiver and an antenna, which is controlled by specialized software from a computing center [10].

Each base station knows the exact position of the phase center of the navigation receiving antenna, allowing the current coordinates of the phase center of the navigation antenna to be determined at any epoch by solving the navigation problem. Knowing the exact coordinates of the antenna

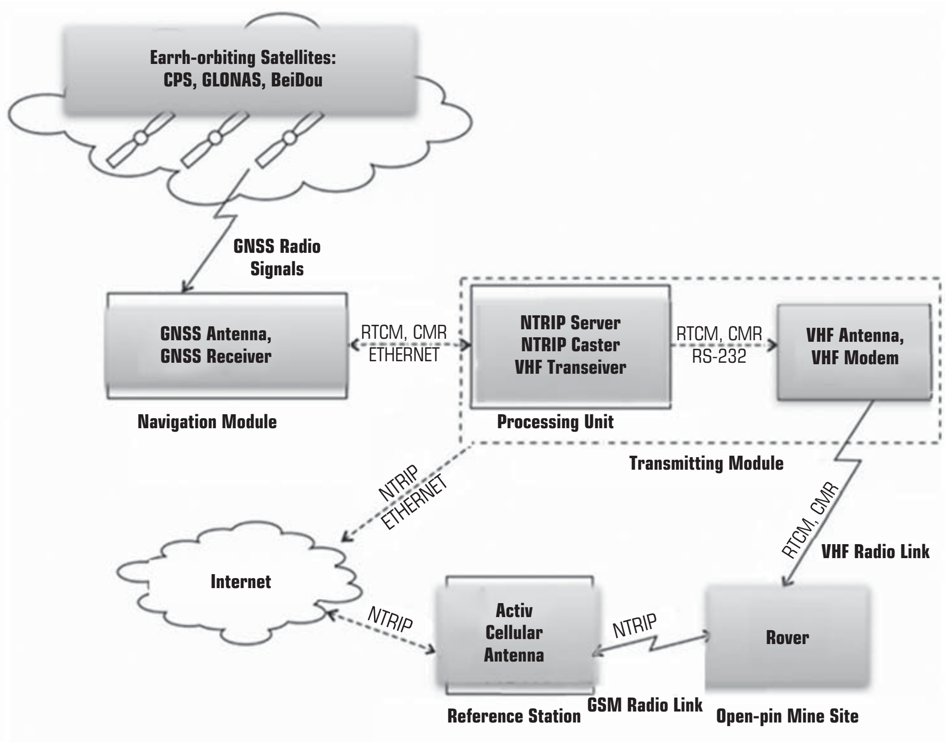

Fig. 1. Data transmission at differential correction base station

comprehensive research methodology has been developed, focused on the effective application of GNSS signal differential correction technology. The scientific research keeps up the following algorithm: development of project documentation for the reference geodetic network and the differential correction base station (including preliminary and technical projects); development of mathematical support and software for processing satellite measurement data; manufacture of the geodetic point and Differential Correction Base Station (DCBS); creation of a differential correction center and a data transmission network; preliminary testing, trial operation and acceptance run.

The formation, transmission and transformation of digital data and primary information are organized in stages as follows [13]:

1) The GNSS antenna receives and amplifies radio signals transmitted on frequency bands from ground space vehicles (GSV) of GPS (American Global Positioning System), GLONASS (Russian Global Navigation Satellite System) and BeiDou (Chinese Satellite Navigation System).

2) The GNSS receiver takes in signals from the antenna and demodulates signals GPS L1/L2, GLONASS L1/L2, BDS B1/B2/B3, decodes useful information from these signals, produces estimative measurements of distances to visible GSVs of GPS, GLONASS and BeiDou, solves the primary navigation task to determine the coordinates of the GNSS antenna phase center, then stores these data in memory, and forms differential corrections in terms of RTCM (Radio Technical Commission for Maritime Services) and CMR (Compact Measurement Record by Trimble) messages.

and the calculated values of the antenna coordinates, corrections to the pseudoranges can be determined, which need to be transmitted to the mobile receiver of the consumer. Using the transmitted corrections to the pseudoranges, the amended high-precision coordinates of the phase center of the mobile receiver antenna are determined on the user's mobile receiver. In this manner, differential correction of GNSS navigation signals is carried out [11, 12].

To achieve the goal of determining geodetic coordinates using modern satellite navigation technologies in real-time and post-processing modes, a

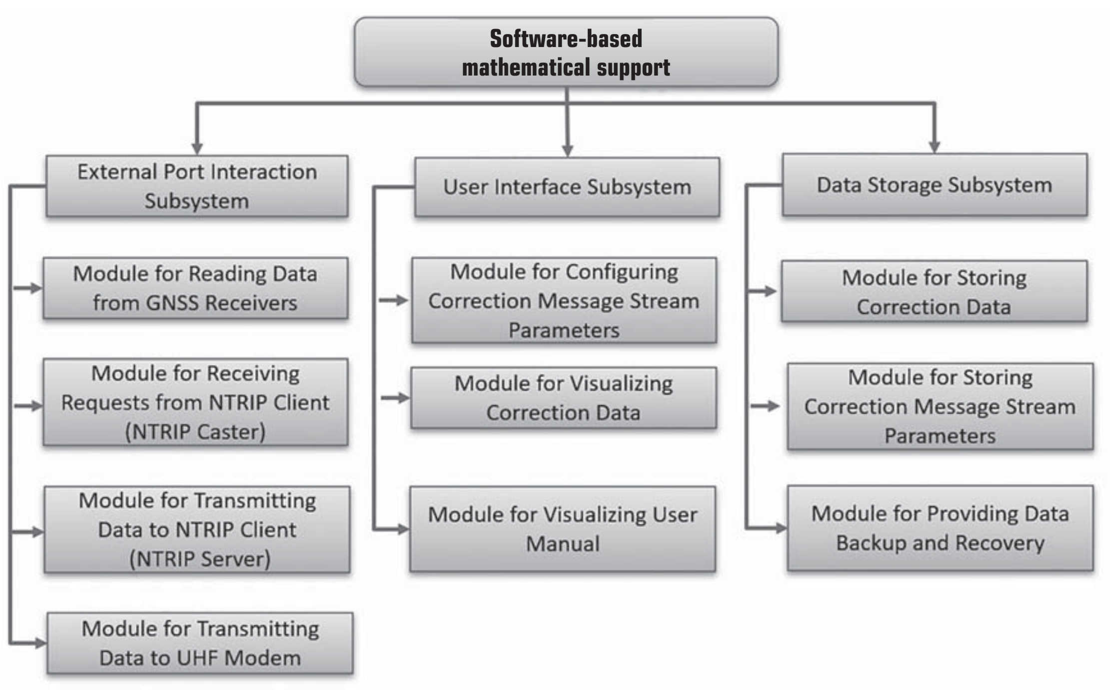

Fig. 2. Structure of software-based mathematical support for processing satellite measurement data

3) A computer equipped with navigation measurement processing software receives the stream of correcting information (CI) via the quarry's local Ethernet network from the GNSS receiver; next, the CI stream is decoded, and based on the decoded data, two parallel streams are formed; the first stream of RTCM and CMR messages through the serial port is directed to a UHF modem; the second stream of NTRIP (Network transport of RTCM frames via the Internet Protocol) messages, formed based on RTCM messages, is directed through the local Ethernet network (a family of technologies for packet data transmission between devices for computer and industrial networks) of the quarry into the Internet network.

4) The UHF radio modem receives RTCM and CMR messages from the computer, modulates them to a designated radio frequency, and directs the CI to a directional antenna, which in turn transmits differential corrections through the UHF radio link.

5) NTRIP messages from the Internet network are directed to the base station of the Kcell ACTIV mobile operator and transmitted via a corresponding antenna, which is fixed on the antenna mast near the Dispatcher's building, through the GSM radio link.

6) A rover located on the rim or bottom of the quarry receives CI through the UHF radio channel and/or the GSM radio channel and, based on the received differential corrections and its own satellite navigation measurements, performs high-precision calculation of its coordinates in RTK (Real Time Kinematic) mode. The described method of data transmission organization in DCBS is presented in **Fig. 1**.

The described method of data transmission organization is the most economically feasible as it meets all functional requirements imposed on DCBS while maximizing the use of infrastructure already present at the quarry site.

The developed software-based mathematical support (SMS) for processing satellite measurement data is structurally divided into three subsystems: a subsystem for interacting with external ports; a user interface subsystem; and a data storage subsystem. The overall structure of the SMS is illustrated in **Fig. 2.**

This methodology not only allowed thorough verification and assessment of the capabilities and limitations of the implemented differential correction system but also prepared groundwork for its further development and integration with other technological solutions at the site. The data analysis and system efficiency evaluation also includes the use of statistical methods to assess the reliability of the obtained data and verify the corrective adjustments, which is crucial for maintaining the required level of quality and accuracy in the long term. This implies regular checks and calibration of the system to adapt it to the changing conditions of the quarry operation and the external environment.

Telecommunication solutions

The Differential Correction Base Station (DCBS) is divided into navigational and transmission modules for high-precision satellite measurements, which are located in the Kacharsk Mining Management building and the Dispatcher's office6 respectively (**Fig. 3**). This arrangement was selected upon for four main reasons. Firstly, the location of the navigation module away from the quarry avoids issues related to blasting operations and ground vibrations, which could affect the stability of coordinates. Secondly, radio signals used for transmitting differential corrections are ideally transmitted from the close proximity provided by the antenna mast at the Dispatcher's office. The third reason is that the mining management building meets the standards required for satellite geodetic networks. The final reason is the economic feasibility of placing the navigation module of the DCBS in the surveying service office to reduce costs associated with maintaining and protecting the equipment [14].

The mobile module of the DCBS, functioning as an active UHF signal repeater, is integrated into the system only when the power of UHF and GSM signals is insufficient to support the RTK mode. This solution is particularly relevant for quarries with uneven terrain and a high iron content of host rocks, which limits radio coverage and contributes to signal scattering [15]. Installing a repeater on the edge of the quarry enables effective reflection of radio signals into the zone where mobile rovers operate at the bottom of the quarry, ensuring their stable communication in conditions of limited visibility and complex geological environments. The developed scheme for data transmission using a reflective-type repeater is shown in **Fig. 4**.

Active relay systems include multi-component equipment such as one or more antennas, devices for receiving and transmitting

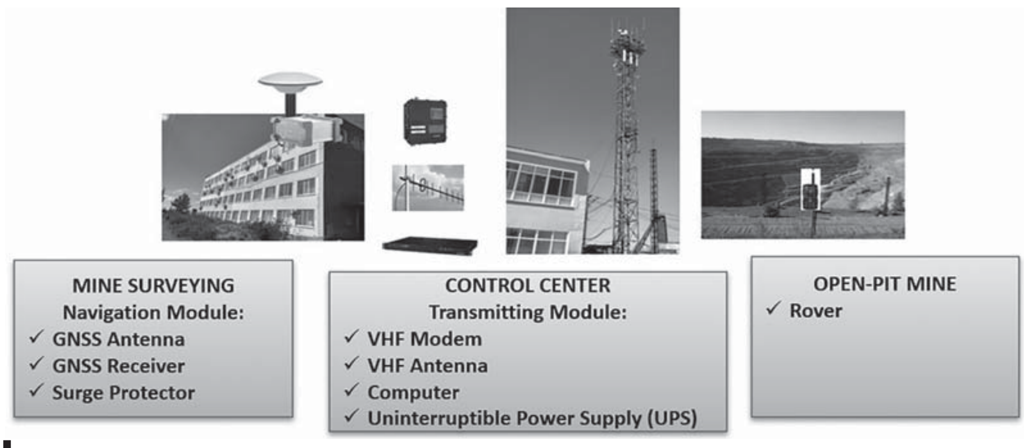

Fig. 3. Layout of modules of Differential Correction Base Station

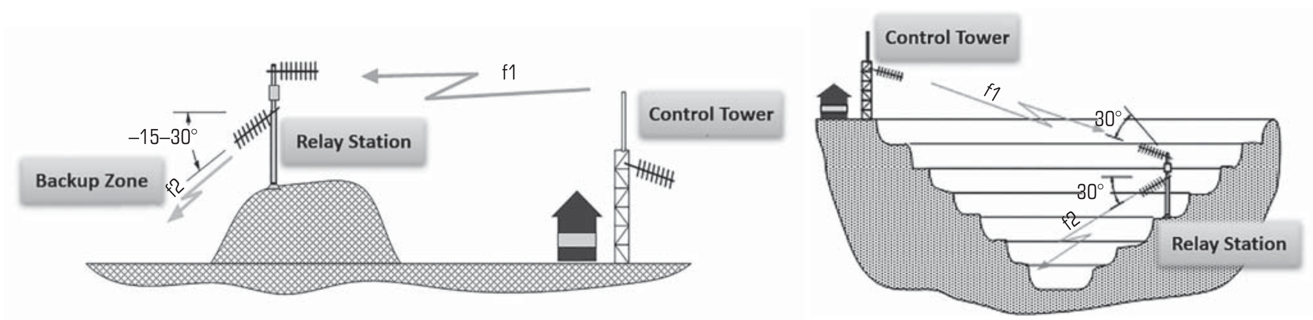

Fig. 4. Antenna orientation when installed on spoil heaps and in the quarry for data transmission using UHF band repeater [16]

radio signals, a power source, as well as tools for remote control and monitoring. These systems are designed to relay radio messages through so-called "shadow zones" where direct communication is obstructed. The repeater captures the signal at frequency f1, amplifies it and then transmits it on another frequency, f2, functioning simultaneously as a receiver and transmitter. This process, known as duplex transmission, ensures continuous communication without delays. Regarding the Kacharsk quarry, the system operates using two frequencies, f1 and f2, to ensure reliable communication for users both at the bottom and at the top of the quarry, all of which operate on frequency f2. This is especially important, even if for users located on the upper rims or on the surface, a direct communication channel on frequency f1 is theoretically available.

Conclusions

Currently, Kazakhstan is striving to develop and implement a high-precision satellite geodetic network, utilizing navigation systems such as GPS and GLONASS. This direction holds significant potential for the country as it allows the expansion of national production, including the creation of differential correction base stations, which in turn fosters the development of a network of reference stations within the country.

Fruitful collaboration with the Institute of Space Technique and Technology demonstrates considerable achievements in this field. The mathematical modeling systems for differential correction are developed, as well as the software-based mathematical support is designed for the high-precision positioning tasks, and numerous R&D works are implemented. These developments enable efficient design and production of differential correction base stations (DCBS) and mobile receivers necessary for a high-precision positioning system. The technologies used to create the base stations and mobile receivers are fully compliant with global standards used by leading international companies.

The development and application of high-precision satellite technologies open new horizons for various sectors of the economy, including construction, agriculture, transport and environmental monitoring [17]. This is especially important for the mining industry, where the requirements for measurement accuracy in monitoring are particularly high. The implementation of satellite technologies enhances the efficiency of natural resource use, reduces the environmental impact and ensures the work safety.

The results obtained during the study not only ensure high accuracy of geodetic measurements in the challenging conditions of the quarry but also significantly increase the efficiency of managing mining operations through precise and reliable navigation of mobile and stationary objects.

Ultimately, the application of the developed differential correction system can make a significant contribution to the work safety, allowing precise tracking of equipment and personnel movements in conditions of limited visibility. Additionally, the system contributes to improving the environmental situation at the site by enabling more accurate planning of developments and minimizing geological interventions.

Research and development in this area remain open to innovations and improvements, implying the potential introduction of new technologies and methods that can be integrated into the existing system to further enhance its effectiveness and adaptability. Such improvements can include the development of machine learning for automatic data analysis and prediction of potential errors, as well as the use of artificial intelligence to optimize the process of differential correction in real-time.

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