A System for Monitoring the Position of Brown Coal Bucket-Whell Excavators and their Operational Safety

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Abstract

The purpose of the system for real-time tracking of mining excavator and loader positions is to improve the management and control of brown coal mining in opencast mines and to improve work safety.
The system calculates the wheel excavator position using data from GNSS equipment installed on the giant mining machines, inclinometers and inertial measurement units located on each mining machine. Data are transmitted from the machines and stored in databases on servers. Visualization of the wheel excavator movement in real time is performed in software products of KVASoftware s.r.o., which enables work with a digital terrain model, geology of the deposit and overburden, including objects impairing safety work.
The article describes the procedure of data preparation and setting up the whole system in different levels of KVASoftvare s.r.o. software products. It also describes in detail its use with regard to the safety of work in heavy mining operations, specifically in areas affected by underground mining or areas dangerous due to the occurrence of tectonic deformations in the overburden and in the seam.

Keywords: *bucket-wheel excavator, digital terrain model, GNSS, brown coal mining, photogrammetry, UAV, point cloud, cubic capacity calculation, coal mining safety, tectonic deformations*

1. Introduction

Brown coal mining is still an important industry in the Czech Republic, despite a significant decline in production over the last twenty years. 2018 over 38 million tons of brown coal were mined [1].

Reliable supplies of domestic lignite are a balancing element of the Czech energy sector. In recent years, lignite has still been used to generate just over 40% of the electricity consumed in the Czech Republic [2], up from 43% in 2018.

At present, lignite mining in the Czech Republic is concentrated in several large open pit mines in the "Mostecká Basin" and the "Sokolov Basin" and takes place in increasingly more complicated mining-geological and economic conditions. Therefore, lignite mining companies are looking for additional ways to better monitor, control, plan and subsequently manage the procedures of bucket-wheel excavators and make the entire mining process more technically and economically effective.

One of the important ways of this process is to monitor the spatial position of the bucket-wheel excavator of the mining machines (bucket-wheel excavator and loaders). The system for monitoring the position of the machines is deployed at "Nástup Tušimice Mine, Bílina Mine and Sokolovská uhelná a. s." installation at "Vršany" quarry is under preparation (Fig. 1). Many dozens of excavators and loaders are monitored.

According to the information available from excursions in the past years, a similar system is used at lignite mines in Germany (Mibrag) and in Poland (Belchatow). However, the systems only provide information about the location and the mined masses [13]. They do not deal with geology or safety risks [14].

2. Basic components of the system

All mining companies in the Czech Republic are using a digital format of map documentation for open-pit lignite mining. At Severočeské doly a.s., a complex digital model of the quarry is used – software from KVASoftware s.r.o. called „Báňský model – Mining Model)". It includes not only a digital terrain model but also a digital geological model of the coal seam and overburden layers.

The software enables the creation of maps and provides the means for various calculations and analyses necessary for planning and controlling the operation of the quarry. This software is used as an environment for real-time visualization of the position and movement of mining giant machines.

The " Báňský model – Mining Model" software is followed by the "Technologický model – Technology Model" software,

Fig. 1. View of the Bílina quarry (8/2019) from the south towards the Krušné hory
Rys. 1. Widok na kamieniołom Bílina (8/2019) od południa w stronę Krušné hory

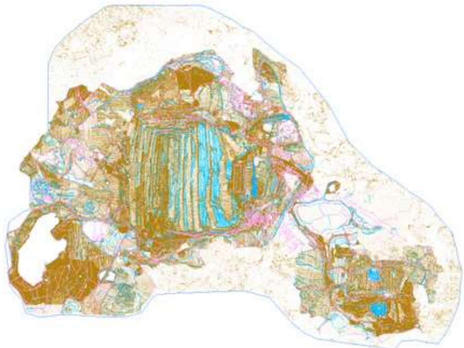

Fig. 2. Digital terrain model including the open pit mine surroundings
Rys. 2. Cyfrowy model terenu z uwzględnieniem otoczenia kopalni odkrywkowej

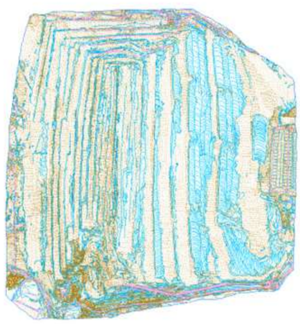

Fig. 3. Digital terrain model reduced to the active open pit mine area
Rys. 3. Cyfrowy model terenu zredukowany do obszaru czynnej kopalni odkrywkowej

which is a reduced version of the Mining Model used for checking the procedures of large machines for the technicians managing the mining. An even simpler version is the " GNSS_Rkabina – GNSS extractor Cabin" program, which is installed on excavators, and the " GNSS_Zkabina – GNSS stacker Cabin" program, which is installed on the stackers. In both cases, it is used by the drivers of the giant mining machines to maintain technological discipline and ensure safety work.

The system for calculating the spatial position of the wheel consists of three basic elements [3]:

- Measuring segment (data collection) (GNSS receivers, receivers and sensors, control unit) [11], [12],
- Communication segment (transfer of data from the instruments to the servers and after calculations back to the large-scale machines and to other users),
- End user segment (evaluation and user software company. KVASoftware s.r.o. – Mining model, Technology model, GNSS extractor Cabin, GNSS stacker Cabin).

By surveying measurements directly on the excavator, the parameters for the derivation of mathematical relations necessary for the calculation of the spatial position of the center of the excavator wheel axis were determined [7]. These are mainly the distances of the individual measuring instruments (GNSS, inclinometers, inclement speed sensors) in relation to each other and to some mechanical "nodes" of the excavator structure [9]. Subsequently, an algorithm [8] was developed that incorporated the results of the measurements of the individual measuring and gauging instruments and allowed calculations of the spatial position of the wheel centre in any general position of the excavator [10]. Somewhat more complex is the modelling of the shape of the material to be placed on the spoil heap by tracked stackers using the throw parabola [4].

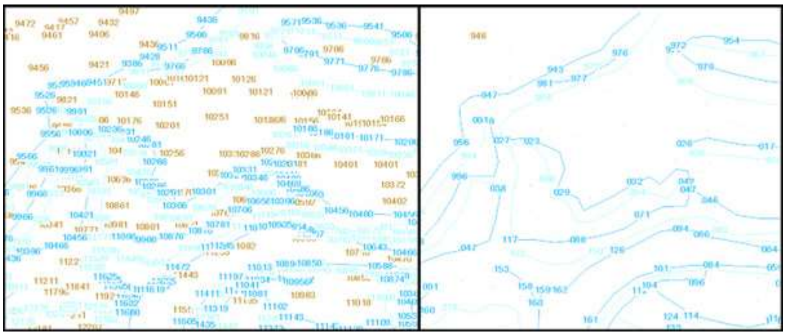

Fig. 4. Reduction of dimensions
Rys. 4 Redukcja liczby warstwic

Fig. 5. DT model
Rys. 5 Model transportu taśmowego w kopalni (DT)

3. Data preparation process and system setup

The "Bílina" (DB) and "Tušimice" (DNT) brown coal quarries are surveyed by digital photogrammetry 10 to 12 times per a year. Until 2021, aerial photogrammetry was used at "Severočeské doly a.s." using manned aircraft, supplied by PRIMIS spol. s r. o. The processing of measurement images, creation of stereoscopic perception, evaluation and creation of orthophoto maps were carried out by the mines' employees in the software INPHO (MATCH-AT , SUMMIT EVOLUTION, ORTO VISTA) Since 2021, the " DRON – MRAČNO – DRON-CLOUD" method has been used for targeting the fracture, which is a photogrammetric method using images taken by a camera carried by an unmanned aerial system (UAV) [5]. In fact the DJI M300 RTK quadcopter with a DJI Zenmuse P1 camera is used. Data processing for terrain models is performed in CARLSON software. The transition to the new method of mapping coal blast furnaces has brought a series of problems. For more information, please see Chapter 6.

The results of the photogrammetric measurements are exported to a *.txt file, where each model line (edge, heel, point on the platform) has its specific designation. When using point clouds, it is practically a "manual vectorization" of point clouds. The *.txt file is further imported into the SW Atlas (DB) or SW KVAS (DNT) environment, which can recognize the model lines in the txt file and create sub-evaluation areas. Subsequently, the overall digital terrain model is updated with the newly evaluated areas. Next to be evaluated is the long-distance belt traffic, which is the basis of the transport technology model (chapter 3.2).

3.1 The digital terrain model update

In order to monitor the position of the excavator wheel in real-time on the current state of the digital terrain model, it is necessary to import the updated terrain model from the sw Atlas and KVAS environment into the Mining Model environment and to modify the imported data or to add other models necessary for the operation of the excavator wheel and loader position monitoring system. The import will produce a digital terrain model of the brown coal quarry and its surrounding area (Fig. 2) in GNL format. This model is data intensive for computing technology, so it is necessary to reduce the model to the active area of the open pit mine (Fig. 3).

For a better visual perception on the screen, the attitude model is rotated north to east. The refraction process is then oriented upwards.

The last step in the preparation of the digital terrain model is to generate a triangular mesh that encloses each point on the model. For clarity, the dimensions are reduced with the selected differentiation (Fig. 4).

3.2 The transport belt model upgrade (DT model)

The long-distance belt-based conveyor model, the so-called transport technology model, abbreviated DT model (Fig. 5), contains information about the mining technology and must also be updated. The updating is done by linking the old belt position to the new one. When connecting or moving the passages, the connection between the individual segments must be maintained so that the overall extraction acts as a whole and thus the flow and calculation of the extracted masses is maintained.

Fig. 6. Risk zones and tectonic faults
Rys. 6. Strefy ryzyka i uskoki tektoniczne

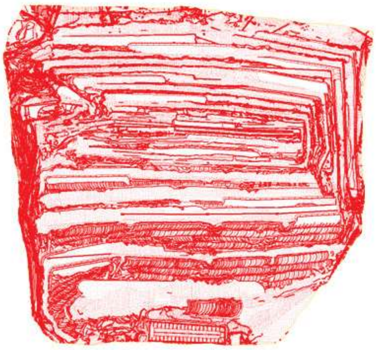

Fig. 7. Digital model of Technical Modes
Rys. 7. Numeryczny model Trybu Technicznego

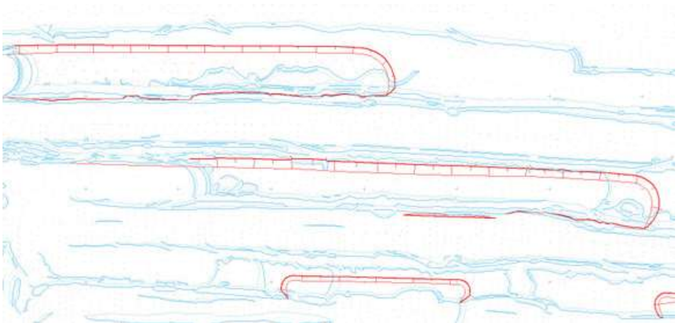

Fig. 8. Planned mining processes
Rys. 8. Projekt procesu urabiania

3.3 The further updates

To complement the excavator and loader wheel tracking system, they update the risk zones, which are areas with frequent tectonic faults (Fig. 6). Separately, the "TEKTONIKA model" is created by geologists. It is a model of the intersection of tectonic faults with the actual and projected terrain, shown in purple color. These zones, tectonic faults, including fractured boreholes, are indicated by the system with a warning signal. For safety reasons, these risks are also physically marked out in the field with wooden stakes in the events of system failure.

The mining pit contains many unlined mine tunnels from the era of underground mining. As there is a risk of mining equipment or persons falling into the unmined areas, for safety reasons a model "HLUBINA – UNDERGROUND" is being created based on old mining maps. As mining progresses, these corridors must be plundered and then secured with wind protection objects. These shortened mine runs must be updated in the HLUBINA model.

3.4 Technical mode

Every month, the Department of Preparation and production of company Severočeské doly a. s. prepares the procedures of wheel excavators and stackers. This is a project of the procedures of large machines and this project is referred to as "technical mode" (TR). These processes are based on the digital terrain model and create the boundary of quarrying and stacking at each stage (Fig. 7). The creation of the technical mode in the Mining Model is similar to the creation of the digital terrain model. For clarity and to differentiate the TR model from the digital terrain model, the TR model is supplemented with stockpiles marks of the spoil, coal, and embedment's. After the technical model is created the TECHNICAL MODE takes data a do converts by simply copying the data into the Mining Model directory as a so-called reference model.

3.5 The data completion

In order for the excavator and loader tracking system to contain complete information, it is necessary to combine the models created into a unified dataset. The digital terrain model creates the base model, to which the models "TEKTONIKA, TECHNICKÝ MODEL a HLUBINA" are subsequently connected. For information on the composition of the rock

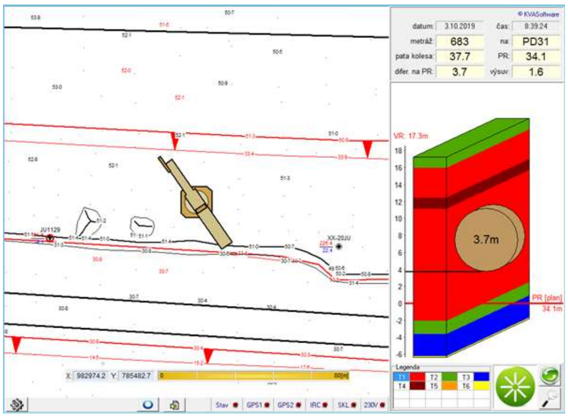

Fig. 9. Model GNSS Rkabina – GNSS extractor Cabin the current position and height of the excavator on the screen in the cab of the mining giant machine

Rys. 9. Model GNSS Rkabina – ekstraktor GNSS Kabina z aktualnym położeniem i wysokością koparki na ekranie w kabinie wielkogabarytowej maszyny górniczej

Fig. 10. The driver's cabin of the mining giant machine – on the right the screen with the "GPS cab" application

Rys. 10. Kabina kierowcy wielkogabarytowejj maszyny górniczej – po prawej stronie ekran z aplikacją „GPS cab"

mass, a geological model is added, which is created and updated by the geology department.

THE TECHNICAL MODE model is based on a digital terrain model, it contains many identical/similar vectors that unnecessarily overtake too much of the computer memory. This load is solved by deleting these vectors, taking only the vectors representing the planned procedures (Fig. 8).

3.6 The Cabin model

In order to get all the created data onto the screens in the cabin of the excavators or loaders, a so-called "model KABINA - CABIN model" must be created (Fig. 9). This is the compressed data for the "GNSS_Rkabina – GNSS extractor Cabin" and "GNSS_Zkabina – GNSS stacker Cabin" programs. These are the applications that help the drivers in the control of the mining giant machines equipment. They display in a simplified form information about the position of the giant mining machine, the geological structure of the rock mass at the mining site and the projected procedure (technical mode), including safety risk objects. Both KABINA´s models are then distributed on portable media to computers on each of the giant mining machines.

4. Applications, what the system allows

Applications have been developed in the software Mining Model environment that provides the necessary tools for controlling and managing the mining process. With wheeled excavators, it is important to keep the dimensions and shape mining block. In the KABINA model, the driver of the excavator has tools that make it easy to keep to the specified level of the working plain and the area of the excavation (Fig. 10). Data on the position and height of the wheel every 5 seconds gives him immediate feedback. This is important both for the overall mining concept and for the dewatering of the mine workings. Figure 9 and volume: 17.3m is the actual cut height. This helps to maintain the prescribed cut height limit, which has a positive effect on slope stability.

The technicians have the possibility to immediately check the implementation of the plan - for example, the parameters of the approved Technical Mode for the month in the "Technologický model – Technology Model" software. Figure 11 shows the situation at the KU300.8/68 excavator on 1 October 2019 at 8:47 AM. It shows the initial state, i.e. the oriented coal section as of 29.8.2019 (1), the Technical Regime for October 2019 (2), the schematized position of the excavator at 8:47 am (3) and the vertical profile of the coal seam with the wheel position (4) in real-time. The red horizontal line in profile (5) denotes the level of the planned excavator running plane. The profile shows that the lowest point of the wheel is 1.6 m above the planned running plane. From the table in Figure 11, bottom right, we can read some important data about the ongoing mining. On October 1, 2019, at 8:47 a.m., coal was mined with a calorific value of $Qr=16.7$ MJ/kg and an ash content of $Ad=12.81\%$, which is T1 coal (in red in the profile). The shaded grey area on the map shows where the excavator has mined in the past (where the wheel was). Excavator mining or soil placement on the spoil heap can be observed in the spatial view (Fig. 12).

The real-time spatial tracking of the wheel excavator center helps to accomplish one relatively brand-new task very well. This is the creation of map documentation in connection with payments from extracted minerals according to Act No.

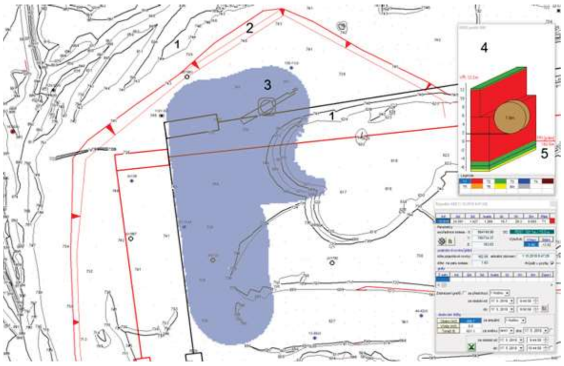

Fig. 11. Application "Technological model" for control and management of mining plan compliance – Bílina Mines, position of excavator K300.8/68 on 1 October 2019 at 8:47 AM

Rys. 11. Aplikacja „Model technologiczny" do kontroli i zarządzania zgodnością z planem górniczym – Kopalnia Bílina, stanowisko koparki K300.8/68 w dniu 1 października 2019 r. o godz. 8:47

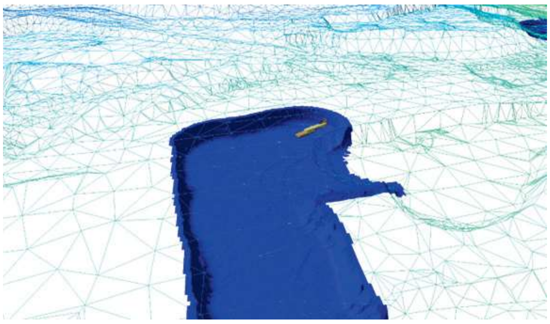

Fig. 12. Excavator K300.8/68 on 1 October 2019 at 8:47 AM. in 3D

Rys. 12. Koparka K300.8/68 w dniu 1 października 2019 r. o godzinie 8:47. w 3D

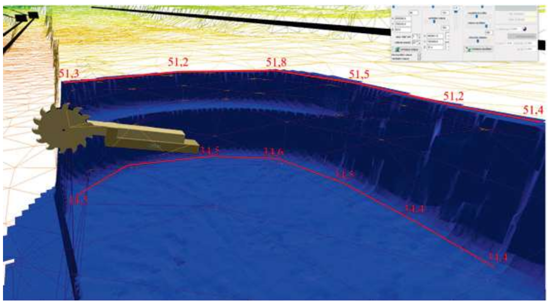

Fig. 13. The principle of digitizing the status of the coal cut – excavator KU300.40/102 on October 1, 2019 at 11:52 a.m. in 3D

Rys. 13. Zasada digitalizacji stanu urobku – koparka KU300.40/102 1 października 2019 o godzinie 11:52 w 3D

225/2017 Coll., amending Act No. 44/1988 Coll. on the protection and use of mineral wealth (Mining Act). This Act regulates the reimbursement from lignite extraction by opencast mining in such a way that the partial basis of the reimbursement from lignite extracted by opencast mining is the amount of heat contained in the extracted lignite in a calendar year. The system makes it possible to obtain the state of coal cuts exactly as of 31 December, 24:00 of the current year, by creating a vector map at that moment from a spatially visualized model of the state of the cut. By hovering over any point on this spatial representation of the cut (in blue in Figure 13), X, Y and Z coordinates can be obtained and vectors of, for example, the top and bottom edges of the cut can be created. By "evaluating" the new state in this way, the base model can be updated at a date beyond the standard aerial photogrammetry evaluation date and the appropriate map documentation can be produced.

The evaluation (vectorization) of the mining line state is similar to photogrammetric systems. The evaluator selects the code of the line to be evaluated, for example, the upper edge of the section, and selects the first point of the line in the digital map (in Figure 14 in the left window). Then he switches to the spatial view (in Figure 14, right window) and finds the points of the upper edge. In the 2D view, a polygon of the top edge is created with the points. It then selects the code of, for example, the lower edge of the cut and evaluates the line. Finally, it evaluates the points on the platform created by the excavator procedure and the new state of the cut at the selected date and time is evaluated.

Mining Surveying:

The driver of the giant machine can see the relations of the mining wheel and the displayed mining lines and selected objects on the computer screen located in his cabin. Some measuring activities are reduced or duplicated (safety increase):

- surveying and indicating of excavator mining procedures,

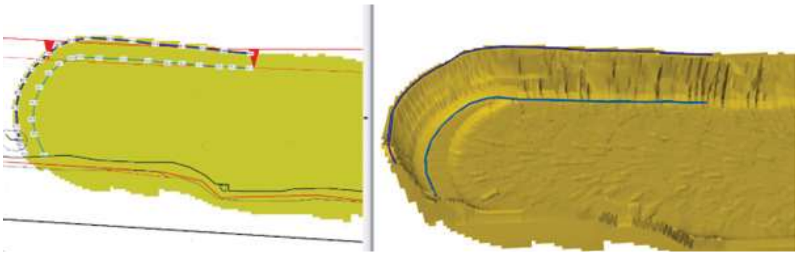

Fig. 14. Condition assessment of excavator KU300.40/102 on 3 October 2019 at 18:02
Rys. 14. Ocena stanu koparki KU300.40/102 w dniu 3 października 2019 r. o godz. 18:02

- surveying and indicating boreholes with abandoned equipment (which can damage the rubber belt of conveyor belts),
- surveying, indicating and marking certain areas of former underground mining (e.g. chambers, shafts, corridors),
- surveying and marking tectonic lines,
- the software allows us to perform approximate calculations of the volumes of extracted materials.

Geology:

The driver of the giant mining machine sees the relationship between the wheel and the geological layers on a PC screen located in his cabin. This allows him to better orient himself in following the designed mining trails in the profile descriptions (profile passport).

Production:

- The Production management and back-monitoring of production targets have been improved, essentially in real-time,
- An application has been developed that allows the big rig driver to adhere much more accurately to the designed cutting geometry, especially the height levels of the excavator working planes. At the same time, it is possible to verify when a possible violation of the design procedure has occurred and therefore by which responsible employee,
- The overview of the quality parameters of the currently mined coal for all excavators comes.

Geotechnics and Mining Safety

- The "GNSS_Rkabina" application, which is used by the driver of the large machine, provides information on the current cutting height achieved in addition to the data for technological discipline. Compliance with this will have a positive effect on slope stability,
- The operator of the giant mining machine is also informed of the cased boreholes, the historical deep mining and the degree of danger of the approaching tectonic line and applies the technological procedure prescribed as adequate to ensure slope stability and mining safety in such a case.

5. Applications and occupational safety in open pit mining

Drilled boreholes:

- Boreholes with abandoned equipment (cased boreholes) pose a risk primarily to the mining technology, less so to occupational safety. The rubber belt on the conveyor belt can be damaged when the casing is "loaded", or in a worse case, the excavator can be damaged.
- The drilled boreholes are marked out in the field by surveyors with wooden stakes before the excavator proceeds.
- In addition, the boreholes are displayed on the cabin display. The excavator display changes dynamically according to the current position of the excavator. When approaching a wellbore beyond a specified limiting distance, the surroundings of the well "flash", the current distance of the wheel from the well begins to be displayed and an audible signal sounds (see Figure 15).

Mining in areas affected by underground mining:

- In the areas affected by underground mining, there is a risk of equipment or persons falling into unconfined/unsealed areas. A further danger is the possibility of 'uploading' equipment left in the passages of old mine workings, including in cave-in areas.
- Therefore, similar to boreholes, these mine workings are marked out in the field with wooden stakes by mining surveyors.
- The corridors in the driver's excavator cabin are shown in green as lines even with the origin and the broken surfaces are shown as grey polygons.

Mining in tectonic fracture zones [6]:

- In areas where tectonic zones are present, there is a risk of a block of soil/dirt sliding onto the wheel excavator, damaging the wheel or the entire excavator structure (Fig. 16).
- For these areas, company SD a. s. has developed a methodology for determining the level of risk, which is dependent on the orientation of the tectonic fault to the direction of excavator advance, fault dip, section height, and the nature of the fault surface. Faults can thus represent low risk, medium risk or high risk.
- If a break/fracture is assessed as high risk at the time of designing procedures, it is necessary to take early measures for its successful and safe removal at the process of mining preparation.
- Low-risk breaks/fractures will not cause problems during mining.
- For medium-risk break/fractures, risks can be eliminated without significant changes in planning procedures. The mining technology is modified to

improve safety, which can limit mining output at most. It is these faults that the software alerts excavator drivers to.
- The break/fracture is also defined spatially in the software and when the wheel of excavators approaches the plan area of one of the faults, it calculates the overall risk. Subsequently, the fault plan view will appear black on the screen, and the text "WARNING: excavator mining wheel in a geological fracture zone" will appear on the screen, along with the risk value (from a value of 30 upwards). This is also accompanied by an audible signal (Fig. 17).

6. Discussions

The real-time tracking system for excavators and loaders has made a number of changes, usually improvements, since 2008. This has mainly been in the area of user programs fi. KVASoftware s.r.o. All were based on the requirements of end users. Over the years, most of the hardware components of the system have been gradually replaced, including the industrial computers with monitors in the cabs of the drivers of the giant mining machines.

The system was adversely affected by the transition to a new method of mapping DB and DNT velocity quadrats, namely the transition from conventional aerial photogrammetry to the "DRON-MRAIN" method, as mentioned in Chapter 3.

This new method is not commonly used for large quarries such as the "Nástup Tušimice" or "Bílina" mines and brings us many difficulties [7]. Small-scale colour photogrammetry imaging is carried out 8-10 times a year and includes scraper and coal cuts, side shutter slopes and dumps. The areal volume is 39.4 km2 and 23.6 km2 on the DNT. Large-scale colour imaging is carried out twice a year and includes in addition areas for recultivation and pre-fiels. The large-scale LMS volume is 55,3 km2 and 45 km2 on the DNT. This method has many disadvantages on this scale.

The first challenge is the weather. For small-scale open pit, two days of good weather are needed for each site, or one day with two drones. For a large-scale open pit, it is more than double that. One day, or 2–4 hours of good weather, was enough for the aircraft. If, for example, the weather does not favour it in the autumn and winter months, there are delays and cancellations. A further complication of this method is the need for more than twice the number of points in the field to achieve the necessary accuracy (Standard No. 435/1992 ČBÚ). This increased the field measurement work for stabilization and targeting of "VB – ELEVATION POINT" (reference), compounded by delays in image collection work and need to do repeating imaging during bad weather. Last but not least, the final product - point clouds – is a disadvantage. These are only useful for measurement work with "terrain" (cubic volumetric measurements, excavator and loader positions, etc.). They are completely useless for construction object planning, utilities, etc., compared to the aerial photogrammetry used previously. The changes to UAVs has resulted in an increase in measurement work in the field.

The use of two or more drones would be of great benefit for successful imaging, data processing and meeting deadlines. This would eliminate situations where contractual conditions (deadlines) are not met, but also where imaging deadlines are pushed back and "VB – ELEVATION POINT" is at risk of being destroyed. This is mainly the period from October to April when the weather is not suitable.

The new technology, on the opposite contrast, has been very successful in imaging smaller areas from lower altitudes, such as emergency imaging of slip areas on DB or extraordinary imaging of coal stockpiles on DNT.

7. Conclusions

The real-time measurement system for determining the position of the excavator wheel has proven its practical value in more than fourteen years since its deployment in 2009 in opencast brown coal mining. Currently (05/2023) the system is deployed on all 22 excavators of Severočeské doly a.s. At the Bílina site, 7 stackers are additionally equipped with a similar system. The system is a great tool for drivers of giant mining machines, production managers, production preparation technicians and last but not least surveyors and geologists. In addition, it is a great asset in the field of safety. Since 2015, when the Tectonic Fault Risk Assessment System was implemented in the Excavator Wheel Position Monitoring System applications, there have been no landslides that have had such a destructive impact as the K2000/101 excavator landslide on 11 May 2009. Similarly, there were no incidents related to the occurrence of unmined mine pit areas or cased boreholes. Even if all the precautions are taken and the system described above is used, the risks cannot be underestimated.

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Literatura – References

1. Hornická ročenka [Miner's Yearbook] 2018, Czech Mining Authority.
2. Roční zpráva o provozu ES ČR pro rok 2018. Energy Regulatory Office.
3. Vrubel, M., Sládková, D., Talácko, M., New possibilities of GPS technology in mine surveying. In Proceedings of the 13th International Congress of ISM, Budapest, ISBN 978-963-9038-18-9, (2007).
4. Vrublová, D., Vrubel, M., Maňas, I., Nábělková, L., Surveying system for bucket wheel excavators and spreaders tracking as a contribution to automation of mining process at Severočeské doly a.s., In the Proceedings of the International Conference of Geodesy and Mining Surveying 2018: XXV. SDMG conference, 24-26. October 2018, Pilsen. VSB - Technical University of Ostrava, (2018), (in Czech).
5. Dandoš, R., Mozdřeň, K., Staňková, H., A new control mark for photogrammetry and its localization from single image using computer vision. Computer Standards and Interfaces. Elsevier Science, 2017, 56(February 2018), s. 41-48. ISSN 0920-5489. DOI: https://doi.org/10.1016/j.csi.2017.09.003
6. Kapica, R., Vrublová, D., Vrubel, M., The system of tracking the position of the bucket excavator's wheel for prevention of risk situations. Acta Geodyn. Geomater., 15, No. 3 (191), 277–287, (2018). DOI: https://doi.org/10.13168/AGG.2018.0020
7. Dejl, S., Sládek, V., Strahlheim, P., Nová metoda leteckého měřického snímkování na Severočeských Dolech a.s., In the Proceedings of the International Conference of Geodesy and Mining Surveying 2022, XXVIII. SDMG, z. s., conference 2022, ISBN 978-80-248-4644-6, (in Czech).
8. Vrublová, D., Kapica, R., Vrubel, M., Jiránková, E., Přesnost určování prostorové polohy kolesa rýpadel [Accuracy of the spatial position determination of excavator wheels] Zpravodaj hnědé uhlí. Most: Výzkumný ústav pro hnědé uhlí a. s., 3/2015, p. 10-15, ISSN 1213-1660, (2015), (in Czech).
9. Jadviščok, P., Ovesná, G., Konečný, M., Multipath and its manifestations in the real environment of geodetic practice. Geodesy and Cartography. Taylor & Francis, 2016, 42(2), s. 47-52. ISSN 2029-6991. DOI: https://doi.org/10.3846/20296991.2016.1198573
10. Nebojša B. Gnjatović, Srđan M. Bošnjak, Ivan Lj. Milenović, Aleksandar Z. Stefanović, Bucket wheel excavators: Dynamic response as a criterion for validation of the total number of buckets, Engineering Structures, Volume 225, 111313, ISSN 0141-0296, (2020). DOI: https://doi.org/10.1016/j.engstruct.2020.111313
11. J. Benndorf, Mike W. N. Buxton, Sensor-based real-time resource model reconciliation for improved mine production control – a conceptual framework. Mining Technology, 125:1, 54-64, (2016). DOI: https://doi.org/10.1080/14749009.2015.1107342
12. Al-Shrouf, N. Szczepański, D. Söffker, Online feature-based multisensor object detection system for bucket-wheel excavators. Int J Adv Manuf Technol 82, 1213–1226 (2016). DOI: https://doi.org/10.1007/s00170-015-7375-9
13. Hlavatá, M.; Čablík, V.; Fečko, P.; Tora, B. Mining industry waste - legal regulations in the Czech Republic with focus on black coal mining. Inżynieria Mineralna. 2010, Vol. XI, 1(25)-2(26), s. 27-32. ISSN 1640-4920.
14. KIM, Thi Thu Huong; Tran Hong Ha; Bui Khac Luyen; Lipecki, T. : Mining-induced land subsidence detected by Sentinel-1 SAR images: an example from the historical Tadeusz Kościuszko salt mine at Wapno, Greater Poland Voivodeship, Poland, Inżynieria Mineralna, Journal of the Polish Mineral Engineering Society; 2021 vol.1 no.2, s. 41–52, DOI: https://doi.org/10.29227/IM-2021-02-04

System monitorowania położenia koparek i wielonaczyniowych węgla brunatnego i bezpieczeństwa ich pracy

Celem systemu śledzenia w czasie rzeczywistym pozycji koparek i ładowarek górniczych jest usprawnienie zarządzania i kontroli wydobycia węgla brunatnego w kopalniach odkrywkowych oraz poprawa bezpieczeństwa pracy. System oblicza położenie koparki kołowej wykorzystując dane z urządzeń GNSS zainstalowanych na gigantycznych maszynach górniczych, inklinometrów oraz inercyjnych jednostek pomiarowych znajdujących się na każdej maszynie górniczej. Dane przesyłane są z maszyn i przechowywane w bazach danych na serwerach. Wizualizacja ruchu koparki kołowej w czasie rzeczywistym realizowana jest w oprogramowaniu firmy KVASoftware s.r.o., które umożliwia pracę z cyfrowym modelem terenu, geologią złoża i nadkładu, w tym obiektami zagrażającymi bezpieczeństwu pracy. W artykule opisano procedurę przygotowania danych i konfiguracji całego systemu na różnych poziomach KVASoftvare s.r.o. produkty oprogramowania. Szczegółowo opisano także jego zastosowanie ze względu na bezpieczeństwo pracy w ciężkiej eksploatacji górniczej, szczególnie na terenach objętych eksploatacją podziemną lub na terenach niebezpiecznych ze względu na występowanie deformacji tektonicznych w nadkładzie i w pokładzie.

Słowa kluczowe: *koparka wielonaczyniowa, cyfrowy model terenu, GNSS, górnictwo węgla brunatnego, fotogrametria, UAV, chmura punktów, obliczanie kubatury, bezpieczeństwo górnictwa węgla kamiennego, deformacje tektoniczne*