11 APPLICATION OF GPS TECHNOLOGY IN SURFACE MINING

11.1 Introduction

The fact that the satellite system provides data independently of weather conditions, round the clock and anywhere in the world is a major advantage of the system. During the last two decades the satellite technology has been undergoing fast developments worldwide, which has resulted in the use of GPS technology in many fields. In the surface mining industry the GPS has proven to be useful mainly at resolving usual surveying tasks. The option is now investigated of utilisation the GPS technology also for facilitation of the mining process.

11.2 Use of the gps for determination of excavator bucket wheel position

It is obvious that if the 3D position of excavation elements of mining machinery and associated mining mechanisms can be determined relatively accurately, multiple task can be successfully resolved in terms of control of this hardware. As far as brown coal surface mines are concerned, the following topics are of prime interest:

- Facilitation of the process of control of excavator operation (e.g. prognoses of qualitative parameters of coal being mined)
- Calculations of volumes of mined materials in nearly real time.
- Very accurate control of creation of the movement plane of the excavator and immediate control of mining targets.
- Control and checking of associated mining mechanisms (e.g. dozers).

Fig. 11.1 Surface mining – Libouš mine

In 2006 Severočeské doly j.s.c. launched a research project titled "GPS-Aided Determination of the Position of the Bucked Wheel of the K800/103/N1 Excavator". A project was developed, in which all the components of the system were designed, including their positions, as well as systems of data transfers and data evaluation.

The system consisted of three basic elements [6]:

- Measurement segment (GPS, inertial sensors, control unit),
- Communication segment (radio or GPRS communication for reception and transmission of data),
- User segment (evaluation software).

On bucket wheel excavator K800/103 (fig. 11.2) the measurement segment originally (2006) consisted of 2 DGPS devices Trimble DSM 232 (Dot 1, Dot 2), 2 inclinometers (Dot 3, Dot 4) and one incremental rotation speed sensor (Dot 5). Corrections for DGPS were transferred from the reference station to the excavator employing a radio-modem. A control unit controls the operation of the entire system. The position of the centre of the bucket wheel axis (Dot 6) is computed from X, Y, Z coordinates acquired from the GPS devices and on the basis of sensors' data (inclinations, rotation speeds) on a 5-second basis. Using radio-modems, the data is transmitted to the headquarters building of the Surveying and Geology Department, where it is saved. Then the data is processed by evaluation software (Kvas Prognosis Models). The system has been operated since December 2006.

Fig. 11.2 K800/103 excavator

11.3 The research programme

The data transferred is saved in database file *.DB. All the values measured are saved in this database. On a five-second basis the database should be updated with a series of newly measured values. The first tools have already been developed in the "KVAS - Prognosis Model" programme for visualisation of the excavator and utilisation of the results of computation of the position of the centre of the bucket wheel axis.

The section of digital operational map in fig. 11.3 shows the position of schematized K800/103 excavator. On the left hand side, the vertical geological profile is shown in simplified terms. The position of the bucket wheel in relation to the profile in the relevant site can be seen. The individual types of coal are colour–discerned on the basis of qualitative parameters. Mining plan for excavator is also shown (red lines) as well as boreholes. Another view is on fig. 11.4. The current status and the history of qualitative parameters of the coal (Elevation of bucket wheel - 1, Heating Value Qr – 2 and sulphur content Sd – 3), as derived from the model, can be seen in the left part of the figure.

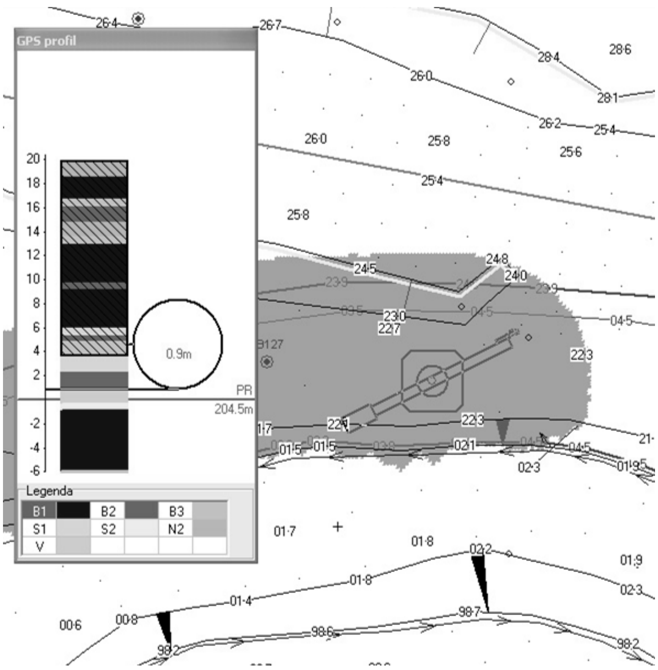

Fig. 11.3 The position of the bucket wheel excavator in real time (map and profile)

The measured data also serves for detailed analysis of the entire process. The analysis is developed by the Institute of Geodesy and Mine Surveying of the Technical University – VŠB Ostrava. The following is carried out in particular:

- Analysis of data transfer (number of measurements received),
- Analysis of accuracy of individual meters,
  - o Analysis of gross errors,
  - o Analysis of the mean errors of individual measurements and identification of the critical point,
  - o Comparison of computed mean errors with values identified by the manufacturers of all the used meters,

- Analysis of the accuracy of the calculation of the bucket wheel axis centre (mean error propagation),
- Analysis of data during operation of the excavator.

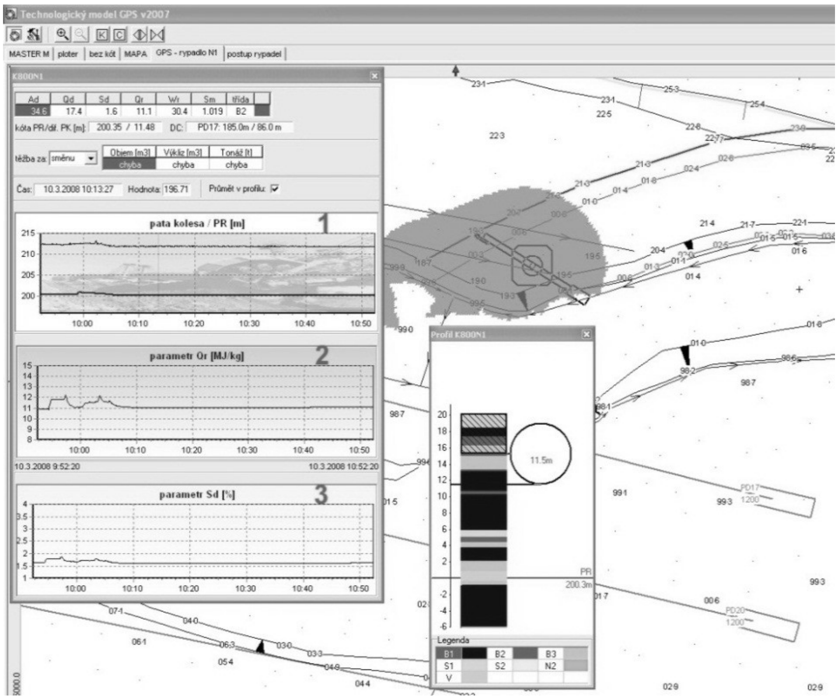

Fig. 11.4 Elevation of bucket wheel and qualitative parameters of the coal (left part of the figure)

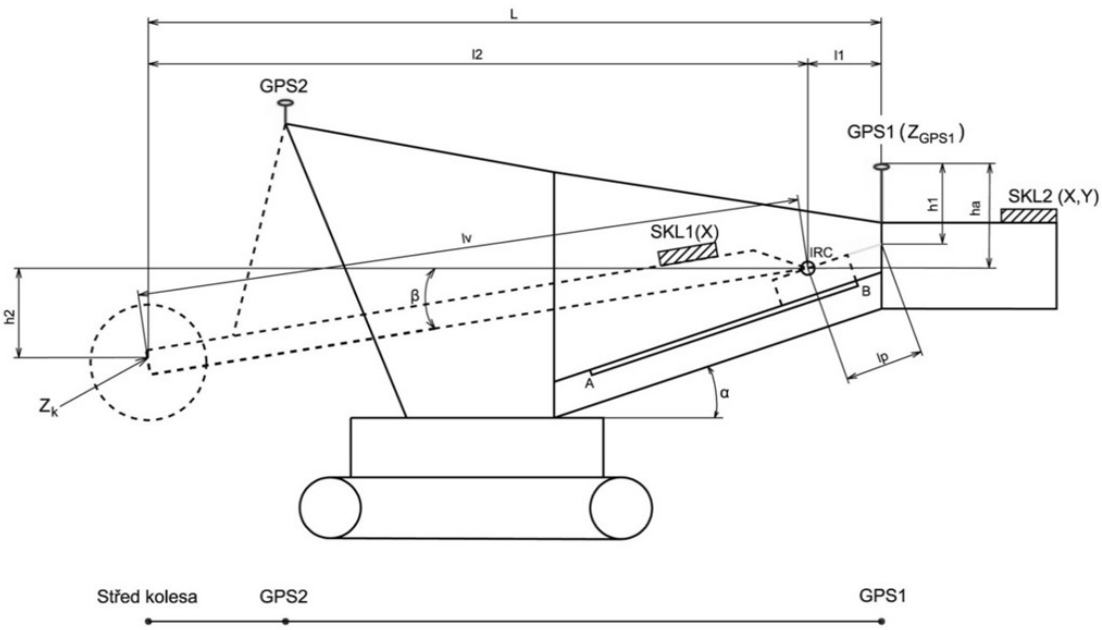

Fig. 11.5 Positions of GPS and inertial sensors at the K800/103 excavator

The basic equations for determination of 3D (XK, YK and ZK) bucket wheel axis position were derived from geometry of excavator and positions of GPS and inertial sensors at the K800/103/N1 (fig. 11.5) excavator:

$$Y_K = Y_{GPS1} + \sin\left(arctg\,\frac{Y_{GPS2} - Y_{GPS1}}{X_{GPS2} - X_{GPS1}}\right)\cdot \cdot\left[\left(7{,}557 + IRC\,\frac{12{,}03}{40423}\right)\cdot \cos\left(19{,}648 - SKL2\_X\right) + \left(35{,}966 \cdot \cos SKL1\right)\right] \quad (11.1)$$

$$X_K = X_{GPS1} + \cos\left(arctg\,\frac{Y_{GPS2} - Y_{GPS1}}{X_{GPS2} - X_{GPS1}}\right)\cdot \cdot\left[\left(7{,}557 + IRC\,\frac{12{,}03}{40423}\right)\cdot \cos\left(19{,}648 - SKL2\_X\right) + \left(35{,}966 \cdot \cos SKL1\right)\right] \quad (11.2)$$

$$Z_K = Z_{GPS1} - \left\{\left[1{,}77 + \sin\left(19{,}648 - SKL2\_X\right)\cdot\left(7{,}557 + IRC\,\frac{12{,}03}{40423}\right)\right] + 35{,}966 \cdot \sin SKL1\right\} \quad (11.3)$$

Accuracy of calculation 3D bucket wheel axis position was derived using of mean error propagation method:

$$m_{Y_K} = \pm\sqrt{\begin{aligned}&\left(\frac{\partial Y_K}{\partial Y_{GPS1}}\cdot m_{Y_{GPS1}}\right)^2 + \left(\frac{\partial Y_K}{\partial Y_{GPS2}}\cdot m_{Y_{GPS2}}\right)^2 + \\ &+\left(\frac{\partial Y_K}{\partial X_{GPS1}}\cdot m_{X_{GPS1}}\right)^2 + \left(\frac{\partial Y_K}{\partial X_{GPS2}}\cdot m_{X_{GPS2}}\right)^2 + \left(\frac{\partial Y_K}{\partial IRC}\cdot m_{IRC}\right)^2 + \\ &+\left(\frac{\partial Y_K}{\partial SKL2\_X}\cdot m_{SKL2\_X}\right)^2 + \left(\frac{\partial Y_K}{\partial SKL1}\cdot m_{SKL1}\right)^2\end{aligned}} \quad (11.4)$$

$$m_{X_K} = \pm\sqrt{\begin{aligned}&\left(\frac{\partial X_K}{\partial Y_{GPS1}}\cdot m_{Y_{GPS1}}\right)^2 + \left(\frac{\partial X_K}{\partial Y_{GPS2}}\cdot m_{Y_{GPS2}}\right)^2 + \\ &+\left(\frac{\partial X_K}{\partial X_{GPS1}}\cdot m_{X_{GPS1}}\right)^2 + \left(\frac{\partial X_K}{\partial X_{GPS2}}\cdot m_{X_{GPS2}}\right)^2 + \left(\frac{\partial X_K}{\partial IRC}\cdot m_{IRC}\right)^2 + \\ &+\left(\frac{\partial X_K}{\partial SKL2\_X}\cdot m_{SKL2\_X}\right)^2 + \left(\frac{\partial X_K}{\partial SKL1}\cdot m_{SKL1}\right)^2\end{aligned}} \quad (11.5)$$

$$m_{Z_K} = \pm\sqrt{\left(\frac{\partial Z_K}{\partial Z_{GPS1}}\cdot m_{Z_{GPS1}}\right)^2 + \left(\frac{\partial Z_K}{\partial IRC}\cdot m_{IRC}\right)^2 + \left(\frac{\partial Z_K}{\partial SKL2\_X}\cdot m_{SKL2\_X}\right)^2 + \left(\frac{\partial Z_K}{\partial SKL1}\cdot m_{SKL1}\right)^2} \quad (11.6)$$

The equations (11.4) – (11.6) for mean errors m_{X_K}, m_{Y_K} and m_{Z_K} of X_K, Y_K a Z_K calculation we got using partial derivation. The final equations are quite extensive therefore we do not bring them in the article. We appointed values of mean errors individual measurement instruments to equations (11.4), (11.5), (11.6) (final version) and have obtained mean errors m_{X_K}, m_{Y_K} and m_{Z_K} influenced by accuracy of individual measurement instruments.

11.4 Partial conclusions from the research project (2007)

The accuracy of determination of the position and elevation of the centre of the wheel axis depends also on the reliability of transfer of corrections from the reference station to the excavator as, unless the corrections are transferred from the reference station to the excavator, GPS receivers switch automatically from the DGPS mode to the "navigation" mode – with considerably compromised accuracy. The first results of data analyses showed that it would be necessary to ensure better quality transfer of corrections from the base to the excavator and vice versa – the success rate was about 70%. This, consequently, had a negative impact on the accuracy of the GPS measurements.

The first results already suggest that for the purpose of routine application, the RTK regime will have to be used and the GPS receivers will have to be upgraded, particularly due to the need to increase the accuracy 3D position determinations. Using D-GPS technology we achieved average accuracy of determination of the position and elevation of the centre of the wheel axis:

$$m_{X_K} = \pm 0{,}164 \text{ m}$$

$$m_{Y_K} = \pm 0{,}143 \text{ m}$$

$$m_{Z_K} = \pm 0{,}265 \text{ m}$$

11.5 The results of development in 2009

On the results of our analysis, SD Company has realized two important changes:

- Radio communication for reception and transmission of data was displaced by ***GPRS system***
- 2 DGPS devices Trimble DSM 232 were changed by 2 ***RTK Leica MNS1230 GG***. The Leica MNS1200 GNSS is specifically designed for construction and mining machine operation at toughest conditions.

The results of accuracy analysis are better now and for main future purpose – prognosis of qualitative parameters of coal to be mined in near future (short term prognoses) – are satisfying. Data transfer success rate is better than ***99%*** and average accuracy (RMS) of determination of the 3D position of the centre of the wheel axis:

$$m_{X_K} = \pm 0{,}025 \text{ m}$$

$$m_{Y_K} = \pm 0{,}012 \text{ m}$$

$$m_{Z_K} = \pm 0{,}041 \text{ m}$$

11.6 The main goals

After the research programme is completed, a complex system can come into being of measurement of positions of mining mechanisms, which could be beneficial in multiple areas:

Mining of coal, striping and combined haulage levels

- Visualisation of the positions of excavators and their movements and elevations in real time at earmarked computers connected to the network and provided with relevant software.
- Information on the position of the wheel in relationship to the stratum profile or stripping level.
- Saving of mining procedures and their retroactive retrieval in both graphic and numerical forms (checking and analytical purposes).
- Control of creation of movement surface/plane in real time and its immediate checks.
- Computation of qualitative parameters of coal in real time with all excavators and simulation of the functions of the qualitative parameter meters.
- Development of prognosis of qualitative parameters of coal to be mined in near future (short term prognoses).
- Computation of volumes of mined materials in real time (the volumes of mined materials will be known with almost "surveying" accuracy immediately after the relevant period – day/month).
- Measurement of extension of the wheel boom.

Facilitation of the Operative Control of Mining

- In a modified form, the applications can also by used in notebooks and PDA. The data can hence be available anywhere in the field.

Mine planning

- Automatic and continuous updates of the condition of haulage levels in the mining model.
- Checking of adherence to technical regimes, including mine planning maps or long term mining goals (position and elevation parameters of advances).
- Determination of the initial conditions for preparation of next month's advance on the basis of actual advance in the ongoing month. Continuous calculation and detailing of the limits of start and end of advance in the next month (period).

11.7 Conclusions

The process of mining of industrial minerals in rather complicated geological conditions (variable morphology and qualitative parameters – both vertically and horizontally, occurrence of idle underground mines etc.) cannot be presently fully automated, as is nowadays commonplace in. e.g. electrical engineering, in industry of manufacture of simple mechanical engineering products or in the food industry. Nevertheless, the developments in information technologies as well as in other technologies enable to expedite the feedback within the line of “planning – implementation-check”. Information on where an excavator operates and what is being mined can be acquired (with some degree of inaccuracy) immediately. It is critical now if such mechanisms can be created that can exploit this data and influence the production process. In the meantime we are at the beginning of resolving the task, to which multiple disciplines will have to contribute. Through resolving the issue of accurate and reliable determination of the 3D position of the operating machineries and associated mechanisms in mines, the mining engineers, surveyors, geologists, reclamation engineers and managerial staff will acquire a tool for better control and ensuing checks of production processes during open cast mining of industrial minerals.

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