Tests of a longwall shearer diagnostic system using infrared camera

Abstract

The important role of coal in the global energy sector is unquestionable. Improving the efficiency of extraction of raw materials is one of the main tasks of which are committed to designers of modern mining machines. Therefore, you have increasing importance in the process of mining have support systems trouble-free operation of mining machines. At the KOMAG Institute of Mining Technology diagnostic system has been developed combine with the use of thermal imaging techniques. This is the first in the world this type of solution dedicated to working underground mines potentially explosive methane and/or coal dust. The article presents the results of prototype tests combine diagnostic system using a thermal imaging camera realized on a real object in the mine. They pointed out the advantages and disadvantages developed solutions and formulated appropriate proposals summarizing.

Keywords: thermovision, longwall shearer, diagnostics, detection, mining, image processing.

1. Coal importance

Coal is nowadays the most typically fuel used for the production of electricity. About 40% of the world electricity is produced from the coal, and this proportion did not change significantly in the next decades, does like it or not. Coal reserves have almost all the countries around the world, but reserves are available in about 70 countries. It is estimated that while maintaining current levels of production of electricity from burning coal, coal resources will be exhausted in about 147 years. [2]. Other sources talking about 200 years or more [3]. In contrast, proven oil reserves and gas reserves are respectively 41 and 63 years respectively at current production levels. Citing abundant sources at current consumption proven reserves of uranium ore is sufficient for at least 50 years. In addition, the use of nuclear energy is limited by the international regulations relating to security, including significant problems associated with disposal nuclear waste. Hydropower appears to be reaching its upper limit [1]. Introduction of energy from renewable sources (about 2% today) although very important, it will take a lot of time and can’t significantly change over several decades statistics shown in Fig. 1. Thus, according to the International Energy Agency (IEA), demand for coal in the year 2050 should be even higher than today.

2. The concept of automatic cutting drum bits temperature analyzer software

Software programme delivered by the manufacturer of VIGOcam V50 camera enables to record the measurement result, among others, in a form of thermovision image and matrix of temperature associated with this image. Analysis of the problem of designing the analyser of temperature of cutting drum bits proves that it is impossible to base only on the matrix of temperature data, as it is difficult to adjust to conditions in which these data were obtained. It would force development of mechanisms of adjustment of fixed thresholds in an algorithm depending on temperature of bits and their surroundings. It would be more convenient to analyse the image to determine image areas where probably the bits are, correlate these information with temperature data, and finally determine average and maximum temperature of bits.

The literature survey shows that processing of images leading to the assumed results can to be limited only to proper filtration of the image [4, 7, 8]. Complex morphological operations, combined with use of advanced edge algorithms and operations of the lowest level, associated with analysis of position of each image pixel, are required [6, 8, 9].

It has been decided that detection of objects on the image will be based on edge detection algorithm. After testing different edge methods the best results were obtained with use of Sobel method. Easiness of adjustment of resulting wire-frame image to further processing stages is the criterion of selecting the method. Large number of simulations shows that it is convenient to use the Sobel method on image with balanced histogram to determine detection thresholds for edge detection algorithm properly, and then to use this method again on the basic image in grey scale with already known detection thresholds. The next steps of algorithm are associated with low-level processing of results, filtration of disturbances, creation, completion and closing the areas on image, as well as processes deciding about classification of given image as the desired one.

Algorithm enables proper detection of position of bits of longwall shearer cutting drum if only there is a significant difference between brightness on thermographic image (determined by detection thresholds) and brightness of background.
In the first version the algorithm operated on input basis i.e. properly parameterized program was started from commands line, input image and temperature matrix were entered, then the program gave the result. Considering the necessity of using the complex algorithms of digital image processing, it has been decided that at the stage of designing and testing of the algorithm, the software program will be in a form of script run in GNU Octave environment. This environment has internal simplifying procedures such as image processing, improves debugging and it can be run on computers with MS Windows, Linux and MacOs operation systems. Due to necessity of running the software both in 32-bit and 64-bit systems, it was decided to use GNU Octave 3.6.1 version. However, GNU Octave software has some disadvantages:

- processing time of a single image is too long;
- GNU Octave, as an open software, does not allow for explicit protection of started source code.

To solve the second problem, the complement application in C++ language, enabling to code script of GNU Octave environment and to run such a script, was developed. To ensure continuous operation, it was decided to write the computer software program in a form possible for compilation, to integrate it with properly created database as well as to ensure proper utilization of input sub-program. C++Builder language with libraries supporting image processing and libraries, which enable communication with thermovision camera via Ethernet port, was used for the algorithm of image analysis, for communication with database and maintenance of thermovision camera.

The software interface is composed of the four main panels (Fig. 2):

- time panel;
- record panel;
- primary data panel (online analyse);
- secondary data panel (data from the past).

After setting time interval on primary data panel, data records from the database will be displayed. Then the required record can be selected and depending on the options set, interesting details of the record can be displayed.

The software tests were carried out in the WindowsXP 32-bit SP3 and Windows7 64-bit operating systems.

3. Tests on a real object

The aim of this study was to verify the functionality, of a diagnostic system with using a thermal camera in the real object (longwall shearer) in the mine. Tests in the real conditions would supply knowledge in terms of the effective functioning of the system developed. It was the first attempt in the real conditions. The scope of study included measurements under real conditions at the mine, using thermal camera VIGO V50 Ex type (Fig. 3) with an extra air-curtain built.

The monitored machine was a longwall shearer. The objects studied in the conduct measurements were cutting bits located on the longwall shearer cutting head. Diagnostic system with using a thermal camera it’s independent system supporting the work of a shearer. Preparing the system for the tests in the real conditions needs a:

- Conducting workshops for the future users. The workshop participants were acquainted with the abbreviated manuals,
- Conducting surveys among participants in order to assess its functionality and service,
- Preparation of a research program,
- Conducting verification tests on the surface, in order to examine the proper operation of all its elements.

Fig. 4 shows the hardware configuration of the system, used during the tests on a real object in the mine.

Communications validation tests between thermal camera and workstation were conducted. On the workstation has been shared remote desktop, which by the local bus station can be operated from the surface (from the dispatcher). Was possible to adjust the starting time of the thermal imaging camera on the local station from the surface level, and depending on the position of the shearer in the wall. The answers from the local station was recorded on a workstation, at the time when the longwall shearer was in the zone of the thermal imaging camera startup. Thermovision camera was suspended on a canopy in the second field of 14th powered roof support. The operator’s stand was located in the main gate 20 meters from a thermovision camera. For data transmission was used single-mode fiber optic cable. Automatic start of the thermal imaging camera was set, at the time of appearance of a longwall shearer in the 20th powered roof.
support. The difference between the place of location of the thermal camera, and the place of its startup depend from the position of the longwall shearer in the wall, position of the center of the longwall shearer cutting head was in relation to the thermal imager approx. 7m closer. The Thermogram in the Fig. 5 shows the highest temperature of the cutting bits which was recorded during field tests of the longwall shearer diagnostic system using a thermal imaging camera. The highest recorded temperature of the cutting bits was close to 87°C. This temperature is, not exceeded allowable surface temperature of machines working in the underground mine, which is defined in the value of 150°C. Picture quality of the thermal imaging is very good, and the service has not a problem to identify individual elements which were registered on the thermogram.

![Fig. 5. Thermogram of operating longwall shearer cutting head [11]](image)

In the Fig. 6 presented the connection of the single rotation of the mining cutting head, which should registered the maximum possible number of the cutting bits.

![Fig. 6. The sequence of thermographic registered during operation of the longwall shearer cutting head [11]](image)

As can be seen thermal images from above, the system of the automatically startup the infrared camera is working properly, registered after each cut of the cutting head located in the specified part of the wall (A, B, C). The above figures show, as after each cut, the startup of the infrared camera is followed from further position of the longwall shearer. This kind of situation results from the "runaway" of the longwall shearer positioning system into the wall. In order to avoid such a possibility in the future, the localization of the longwall shearer in the wall should be verified before each shift, and in the event of any discrepancies, then that kind of the situation should be corrected at the local station. Each registered thermogram, is automatically processed in order to present the results of the thermographic informing about the exceeded temperature in the some areas of the image.

### 4. Analysis of the results

In a Fig. 7 and in Table 1 presented an example of automatic image analysis of the selected thermal image, which was recorded during the tests in the mine.

![Fig. 7. The results of the automatically thermal detection system areas with higher temperature [11]](image)

<table>
<thead>
<tr>
<th>Zone number</th>
<th>Localization</th>
<th>Number of pixels</th>
<th>Max. temp.</th>
<th>Average temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y pixel</td>
<td>X pixel</td>
<td>34</td>
<td>51.3</td>
<td>46.37</td>
</tr>
<tr>
<td>1</td>
<td>205</td>
<td>176</td>
<td>36</td>
<td>55.25</td>
</tr>
<tr>
<td>2</td>
<td>208</td>
<td>217</td>
<td>44</td>
<td>56.12</td>
</tr>
<tr>
<td>3</td>
<td>212</td>
<td>195</td>
<td>69</td>
<td>58.04</td>
</tr>
<tr>
<td>4</td>
<td>203</td>
<td>184</td>
<td>75</td>
<td>62.17</td>
</tr>
<tr>
<td>5</td>
<td>179</td>
<td>206</td>
<td>78</td>
<td>65.32</td>
</tr>
</tbody>
</table>

In the registered thermal image, 6 areas of cutting bits, with maximum temperatures exceeding 50°C was recorded. The temperature limits are defined in the “expert” software before proceeding to tests. The maximum recorded temperature on the thermogram in Fig. 6 is 65°C, and it is more than twice below the permissible surface temperature of machines working in the underground mine, which is defined at the value of 150°C. In the base of the processed thermal image, we can say that automatic image analysis system is working properly, providing the user with clear information on the temperature distribution of the cutting bits of the cutting head of the longwall shearer.

### 5. Summary

The studies, and the workshops, were the first opportunity to test the diagnostic system at the operating conditions underground. Thermograms which were recorded during the field tests of the diagnostic system, each time presented cutting head with a part of the longwall shearer arm. The startup of the thermal imager sequence resulted in a registration of thermal images, allowing the registration of a full rotation of the cutting head, which enabled to
analyse of all recorded cutting bits. An expert system is designed to detect a cutting bit which exceeded a defined temperature, and an indication of the cutting bit with the highest temperature. During the tests, the temperature increase between the first and the third cut was over 40°C. This meant that cutting bits are subject to wear during operation what is a natural phenomenon.

Consumption of cutting drum bits is unpredictable and depends on various factors such as:
- corrugation deck,
- hypertrophy stone,
- feed speed of the longwall shearer,
- the way of wall is conducted.

Developed longwall shearer diagnostic system using a thermal imaging camera it is the first system which is working in the mining real conditions. Enabling ongoing monitoring of the state of the cutting bits after each longwall shearer cut. By using the system, user could check the current state of the cutting bits and plan their replacement. It should be noted that, in order to increase the efficiency of estimating the degree of wear of the cutting bits, the system must collect enough data which would be used in the course of automatic image analysis. Therefore, there is need to gather additional information regarding the work of the longwall shearer in different decks with the use of different types of cutting bits. Unfortunately, this process is very time-consuming. At the same time, after each shift, workers should inspect the consumption of cutting bits. In this manner, it will be possible to store sufficient information which could be used, for the future, respectable wear and tear of the cutting bits.

6. References


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