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► **To cite this version:**

J.L. Fuentes-Cantillana, J.C. Catalina, A. Rodriguez, Jean-José Orteu, Didier Dumahu. Use of Computer vision for Automation of a Roadheader in Selective Cutting Operation. International Symposium on Mine Mechanization and Automation, Jun 1991, Golden, United States. pp.15-1 à 15-10. ineris-00971823

HAL Id: ineris-00971823

<https://ineris.hal.science/ineris-00971823>

Submitted on 3 Apr 2014

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Use of Computer Vision for Automation of a Roadheader in Selective Cutting Operation

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ABSTRACT

A research project on automation of a roadheader in selective cutting operation is being carried out in collaboration by AITEMIN (Spain), CERCHAR and LAAS (France). It implies the recognition of minerals and its distribution at the cutting face, as well as automatic generation and execution of adequate cutting trajectories. The case study is a potash mine in northeastern Spain. Computer vision was selected as the most convenient sensing technique to provide an ore distribution map. A complete system has been developed to perform on-line image processing and boom control at the face. The project is financed by the Commission of the European Community and by the Spanish Institute for Mining and Geology (ITGE).

INTRODUCTION

State-of-the art of automation in roadheaders

Most of the experimental work for roadheaders automation has been centered in the operations which imply cutting a complete section which has a constant profile, or shows only slight changes, and with an arrangement of the cutting sequence subject basically only to the restrictions arising from the geometrical or geotechnical conditions. Nowadays, the market offers systems able to control automatically the cutting of a fixed profile, which are applied to build roadways or tunnels.

The problem becomes more complex, however, when the distribution of the different ores or rocks at the face has to be taken into account, since the cutting sequence will change according to the geometrical distribution of those materials, specially in irregular deposits. The foregoing happens, for instance, in mining operations where ore and waste are found in the face and have to be cut separately to avoid dilution, or if some seams have to be cut before others to improve the cutting operation efficiency. In these cases, it is necessary to provide the automatic control system with sensing devices able to detect environment conditions, as well as with a certain level of

intelligence to take appropriate decisions, so that the system can automatically adapt itself to the natural changes in the geology.

Goals of the Project

The goal of the project is, basically, to study the feasibility of an automated system able to control the selective cutting operation of a roadheader working in an underground potash mine.

For this purpose, the following specific goals were defined:

- a) Evaluation of different techniques suitable for ore identification at the face in normal operation.
- b) Development of data processing tools capable to produce a "face map" representing ore distribution in the face.
- c) Development of a cutting plan generator taking into account selectivity, room cross-section, and cutting head dimensions.
- d) Design and implementation of an adequate control system for the roadheader, with all required sensors and actuators.
- e) Development of control software to conduct a cutting test.
- f) Test of the whole system operation in real conditions under human supervision.

DESCRIPTION OF THE TEST SITE

The system has been tested on an Alpine AM-100 roadheader which is working at present in the Potasas de Llobregat Mine, that exploits an ore body about 50 km² large located some 70 km from Barcelona, in the Northeast of Spain.

The orebody consists of two sylvinite seams, rather close to each other, located at 500 m depth. Although thickness values are very variable, average values are shown in figure 1. Each sylvinite seam actually consists of many alternating sylvinite and halite seams, a few centimeters thick, with very thin clay seams intercalated. On the other hand, the overall orebody is quite undulated and shows a large number of mullocky areas. Due to the foregoing, the mine profitability is rather tight and so productivity and low ore dilution are of major importance.

The operation is implemented in two successive passes, as shown in figure 1, leaving the carnallite as roof, and adapting the operation to the changes in thickness and slope of the seams. Selective cut is performed in every face and, while the ore is conveyed to the extraction shaft, the salt is dumped in the nearby mined rooms.

The mine is currently equipped with 13 Alpine AM-100 roadheaders which provide a total output of 270,000 tpy K2O. The weight of these machines is 95 tons and cutting motor power is 300 kW.

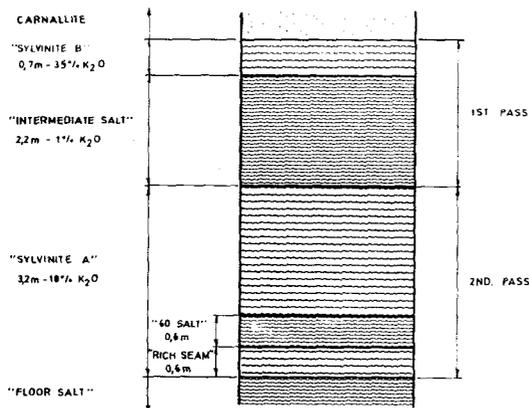


Figure 1. Stratigraphic column of the deposit

MINERAL RECOGNITION

Several techniques to discriminate the different minerals present at the face were tested:

- Natural gamma radiation showed poor spatial resolution and difficulties to be installed in the moving cutting head.
- Microwave absorption was too much dependent on surface conditions such as roughness, water film presence, etc.
- Vibration and noise analysis did not provide possibilities for discrimination in this case.

Finally, vision was selected as the most convenient technique for this application and so most of the research work was devoted to it.

COMPUTER VISION

Spectral Analysis

The feasibility study of vision as sensing technique started with an spectral analysis of the ores present in the mine. The choice of CCD solid state video cameras as sensing devices (for robustness, availability, standard output and cost reasons) restrained the study to the visible and near infrared range of the spectrum, in which those devices are sensitive.

A computer-controlled spectrometric analysis system was set up to measure, store and process reflectance spectra (between 350 and 1000 nm) from each ore sample in a set of 70 blocks composing the complete stratigraphic column of the mine.

The study concluded that colour differences among the ores depended on spectrum shape, not on its level. Halite tends to have a higher relative level in the green range than sylvinite. Thus, if the spectra are normalized at a proper wavelength, ore classification becomes evident. Figure 2 shows average spectra for five minerals after normalization at 525 nm.

In view of the foregoing, it was decided to define a discriminating value, K, as the ratio of:

$$K = \frac{\text{reflectance at } 625 \pm 25 \text{ nm}}{\text{reflectance at } 525 \pm 25 \text{ nm}}$$

Figure 3 shows the values of K computed for all the spectra. The accuracy of such classification is quite significant although there is overlapping between some sylvinite and intermediate salt samples, and carnallite cannot be separated.

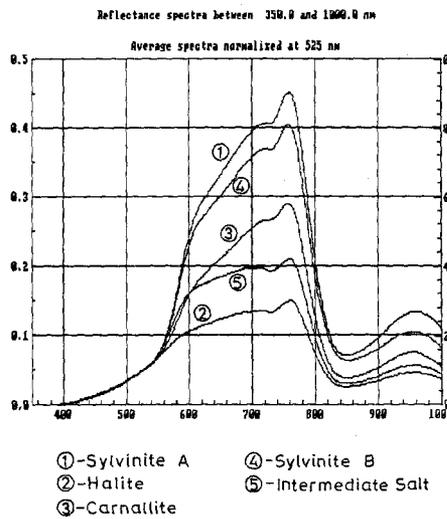


Figure 2. Normalized average spectra

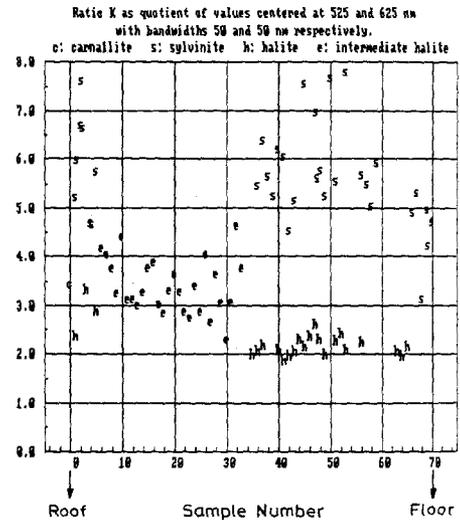
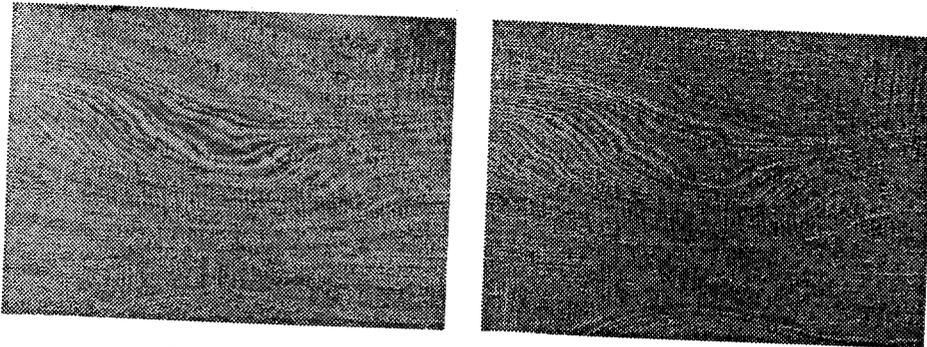


Figure 3. K values for all samples

In order to discriminate the ore distribution in a face it is required to compute the K value at every point. To that end, two monochrome images should be acquired with narrow passband filters centered at 525 and 625 nm, to be then divided point by point. Another possibility that simplifies camera mechanics is the use of a colour camera, as the 525 nm and 625 nm filters can be substituted by the in-built green and red filters, with a small degradation of classification accuracy.

Image processing

The research on image processing algorithms was based on a set of images recorded on videotape in the mine with a professional colour camera, later decoded to RGB and digitized by the image processor.



Figures 4a-4b. Red and green components of a face image

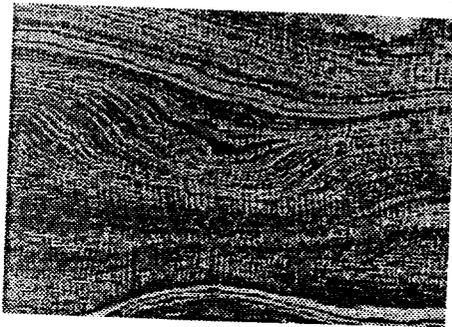


Figure 4c. Reddish seams highlighted



Figure 4d. Segmented image

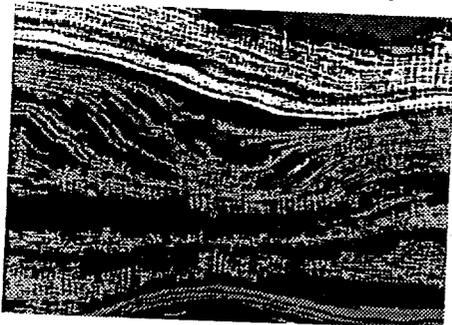


Figure 4e. Classified image

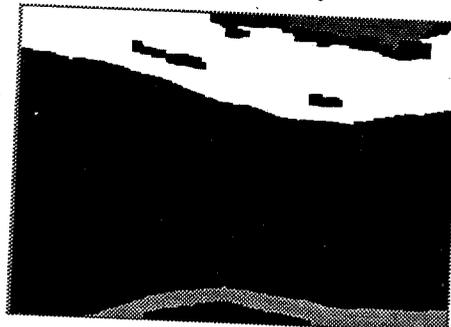


Figure 4f. Homogenized image

The performance of red/green ratio for direct ore classification of individual pixels was too poor to be effective, because of:

- overlapping between K values for the ores, seen in figure 3.
- colour variations in cutting head bit marks on the face.
- noise introduced by camera, recorder and decoder.

Thus, a new processing algorithm was devised to perform classification after region segmentation, to compensate for the variations of pixel colour through averaging. It took advantage of a key characteristic of the orebody: seams of sylvinite, carnallite and intermediate halite, all of reddish colours, are always flanked by halite or clay seams, of unsaturated colours. Region classification was essayed with several techniques, such as split and merge, frequency domain analysis, saturation, R/G ratio, and discriminant analysis, which gave best results.

Image processing algorithm was finally composed of three steps:

- Segmentation: the red/green ratio is combined with a quadratic discriminant function to produce an image highlighting reddish seams, which is thresholded and labelled.
- Classification: four quadratic discriminant functions are applied to the original image over the segmented regions, classifying each of them as carnallite, A or B sylvinite, or halite.
- Homogenization: regions are merged, their outlines simplified, and very small regions are removed, leaving the main seams.

All the above process is performed by software downloaded on the image processor and executed by its own local microprocessor, leaving the main CPU free for other intensive tasks.

Figure 4 illustrates the typical steps in the process of a face colour image acquired at the mine.

Image fusion

In the roadheader being used, there is no safe location for the camera which would provide an obstacles-free view of the whole face. Therefore, it was required to set up two cameras at different locations in such way that they cover areas which complement each other. As a result, the data from two cameras, located at different positions, has to be combined into a single image at some stage of image processing.

The problem of images fusion is solved in two stages:

- A calibration of the system composed by cameras, roadheader and face is initially carried out to determine the conversion equations between their respective reference systems, and to estimate the distortion effects of the wide-angle lenses.

- Through previous equations, any pair of images is transferred to the same reference system and the data from both images is combined in the areas where overlapping exists.

Figure 5 shows an example of image fusion from two different positions and attitudes, with a plane target surface.

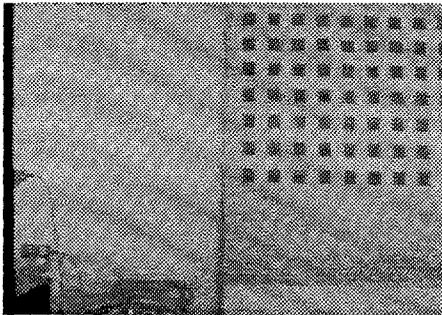


Figure 5a. Left image

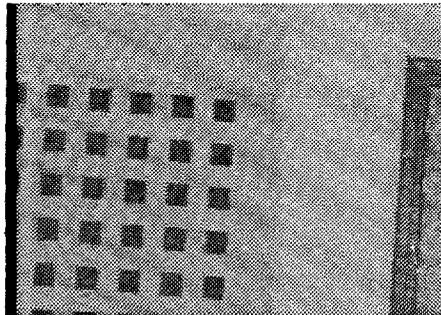


Figure 5b. Right image

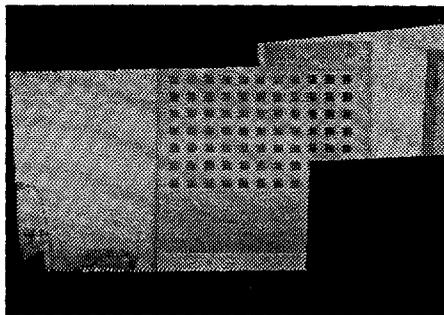


Figure 5c. Image fusion result

Face mapping

Face mapping consists of generating a map of the mineral distribution on a face, in the form of a set of polylines which represent the boundaries between the different seams present in the processed image.

OPERATION PLANNING

Once the face map is produced, a software module generates the most adequate cutting trajectory, which is in principle different for every new cut. This module takes into account the desired final profile, roadheader operational limitations, and

the constraints imposed by loading procedure, shuttle car capacity, and the mining method itself.

By now, no optimization criteria have been introduced in the operational planning, although the produced trajectory is intended to be an "efficient" one.

As an example, a face map as shown in figure 6a would be split into regions as in figure 6b, and cut following the trajectory shown in figure 6c.

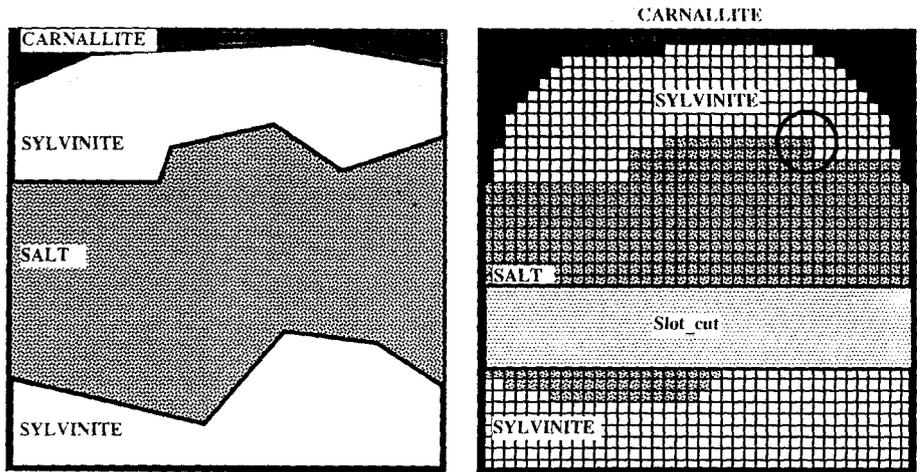


Figure 6a. Face map

Figure 6b. Boundaries redefinition

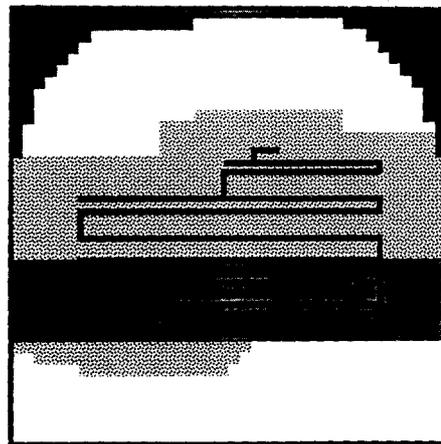


Figure 6c. Cutting trajectory for salt

CONTROL SYSTEM STRUCTURE

The control system is based on a double-computer configuration: a real-time control unit located on the roadheader, and a main unit located outside the mine, in communication through a serial link 4 km long, as shown in figure 7.

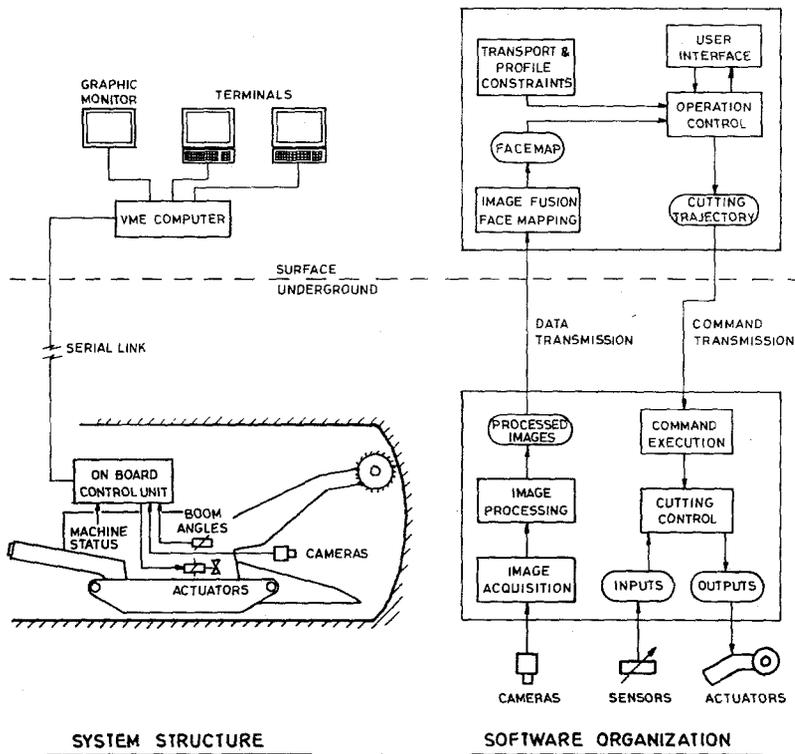


Figure 7. Control system structure

The control unit located at the machine is a diskless VMEbus industrial computer dedicated to acquisition and process of all data from cameras and sensors, and execution of machine control commands and cutting schedules received from the main unit, through actuators on electric and hydraulic equipment. This unit incorporates dedicated hardware such as an image processor and analog/digital I/O and communications boards. The unit is well protected against impacts and vibrations and is equipped with an uninterrupted power supply and its own cooling system since the environmental temperature stays around 37°C.

The main unit at the surface is a VMEbus industrial computer running UNIX dedicated to software development work, remote system monitoring and operation planning and control. To start the system, the main unit downloads the different software modules to the underground unit, until the system is up and running. In this first test, however, the system was controlled from the man-machine interface at the underground unit.

MINE TEST

Conditions in the mine where system test has been conducted were hard, due to the dusty and saline environment, high temperature and distance from the surface. Time available for tests could not be as long as desired, but has been enough to find out the actual possibilities and limitations of the system.

The basic problem found in the mine test was the low quality of the images provided by the video cameras, mainly due to insufficient resolution and poor colour quality (most seams of the face are very thin compared to pixel size), which could not be properly processed by the vision system. But in the developing industrial camera market, probably new products will soon appear providing adequate quality at an affordable price.

Positive results were obtained with:

- Image acquisition: worked well in terms of camera positioning and face coverage, although stronger mechanical protection for cameras and lighting is required.
- Image processing: full mineral identification process worked successfully on the onboard computer with videotaped images.
- Other programs: camera calibration, image fusion, face mapping and trajectory planning programs were tested on the surface computer at the laboratory.
- Trajectory execution and control: worked well although horizontal movement needs adjustment due to nonlinear boom hydraulics behaviour.
- Software structure developed for underground unit based on VERSADOS real-time multitasking kernel operated successfully.
- System hardware: worked properly without major problems, although the protection of some sensors should be improved.
- Communication link between underground and surface computers could not be fully debugged to achieve expected data rate.

FUTURE WORK

A grant has recently been approved by the Commission of the European Community (DG XII) to develop a second phase of this research project. The aims in this new phase are basically to continue with the development, solving the problems found in the previous one and refining the systems and programs produced to make them more robust and less dependent on particular conditions.