

Preliminary Research on Possibilities of Drilling Process Robotization

Stefaniak Pawel ¹, Wodecki Jacek ¹, Janusz Jakubiak ², Radoslaw Zimroz ¹

¹ KGHM CUPRUM Ltd CBR, Sikorskiego 2-8, 53-659 Wrocław, Poland

² Wrocław University of Science and Technology - Department of Cybernetics and Robotics, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

pkstefaniak@cuprum.wroc.pl

Abstract. Nowadays, drilling & blasting is crucial technique for deposit excavation using in hard rock mining. Unfortunately, such approach requires qualified staff to perform, and consequently there is a serious risk related to rock mechanics when using explosives. Negative influence of explosives usage on safety issues of underground mine is a main cause of mining demands related to elimination of people from production area. Other aspects worth taking into consideration are drilling precision according to drilling pattern, blasting effectiveness, improvement of drilling tool reliability etc. In the literature different drilling support solutions are well-known in terms of positioning support systems, anti-jamming systems or cavity detection systems. For many years, teleoperation of drilling process is also developed. Unfortunately, available technologies have so far not fully met the industries expectation in hard rock. Mine of the future is expected to incorporate robotic system instead of current approaches. In this paper we present preliminary research related to robotization of drilling process and possibilities of its application in underground mine condition. A test rig has been proposed. To simulate drilling process several key assumptions have been accepted. As a result, algorithms for automation of drilling process have been proposed and tested on the test rig. Experiences gathered so far underline that there is a need for further developing robotic system for drilling process.

1. Introduction

For hard rock mining applications, drilling & blasting is currently the most popular technology excavation. Usage of explosives creates hazardous conditions for miners mainly due to presence of misfired explosives in blasted ore as well as the highest risk of roof fall in production area. Improvement of quality and effectiveness of drilling operation and removing miners from headings are crucial. Since decades, research in this area is mainly focused on these two aspects. Drilling of blast holes subject to the defined drilling pattern leads to obtain an assumed volume of blasted material and degree of its fragmentation. Second one is key from view point of power consumption of further mining processes (transport, crushing, milling) and their effectiveness [1-2]. It provides faster mine development and consequently an earlier start of copper ore production. Main factors influencing drilling process, in particular are related to lithology that is varying in mining face and experience of the operator [7-10,12]. Drilling in hard and abrasive rock condition, where physical-chemical properties of material are not constant, requires skilful adaptation of drilling parameters to changing external conditions. Furthermore, rock porosity also affects negative reliability of drilling tool [16-18].



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In previous decade one can observe rapid growth of teleoperation solutions that allow removing the miners from headings. Most of them is protected with patent law, a brief description of these approaches are found in the literature. Unfortunately, available technologies have so far not fully met the industries expectation in hard rock. Reliable solution would be robotic system with the possibility of adapting to changing conditions of underground mine in an autonomous way [3,5,13]. Taking into account number of factors influence drilling process and harsh mining condition, development of robotic system should be divided into several crucial steps. First one is to understand of factors influencing drilling process via experiments and further analysis of operating data from monitoring system. Second step is recognition of typical behaviours of operator in different stage of drilling of bore hole and unexpected events. Third one is related to acquiring the data that are needed to teleoperation of drilling process (image 2D/3D, penetration rate, pressures in: the tool feed system, drill's percussion system and drill rotation system etc.). Next one is development of manipulator, its equipment and algorithms which provide drilling operation in laboratory-scale research or as a reference standard. Last one is development of robotic solution in real scale, its testing as well as application in industry.

In this paper we present short introduction to drilling process robotization. The main goal is to test the possibilities for the use of the robotic solution to automation of drilling of blast holes. For this purpose, test rig as well as algorithms have been developed and verified. Many simplified assumptions have been used. Novelty of this paper is insight of development of robotic system for drilling operation in underground mine. The paper is organized as follows: a short review on the subject and current practice in the mining will be described; drilling process will be characterized; based on preliminary analysis, some remark and assumption will be formulated and developed algorithms will be presented; finally, further direction of work based on defined goals of robotic system will be defined.

2. Investigated drilling machine and their operational condition

Typical drill rig of drilling machine (Figure 1) is supposed to drill in a single mining face about 30 holes with 41-76 mm in diameter and 3,2 m deep, in the rock of low, medium and high hardness level. Depending on the purpose drilling holes have different geometry and location. Operational mechanism of the machine is the stepped arm actuated with hydraulic actuators with articulated guiding frame. Rotary-percussive drill with drilling head and bolt slides along the frame.



Figure 1. Self-propelled drilling machine

Blasting holes are drilled according to the drilling pattern, which specifies the amount of holes, their location and geometry. Exemplary drilling pattern is presented in Figure 2a.

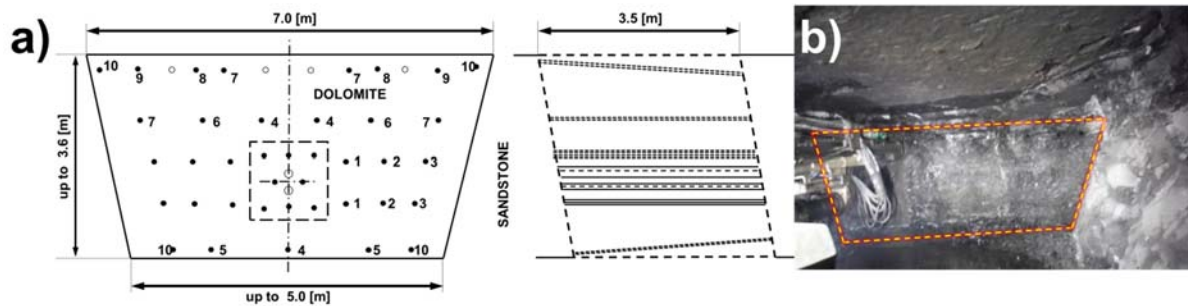


Figure 2. a) Exemplary drilling pattern, b) mining face before drilling process

Drilling patterns take into consideration the character of each exploitation field, geological conditions, rock mass properties, type of drilling rigs assigned for a given front, and other parameters that could influence the effectiveness and quality of blasting and further excavation condition. It is assumed that operator translates drilling parameters from the drilling pattern into the real-world conditions. Unfortunately, in practice it is common that geometric conditions of the mining face such as its surface shape or angles differ significantly (Figure 2b). Improperly drilled holes translate into state of the mining face after blasting, lower amount of blasted material and worse fragmentation. It also happens that low quality of blasting enforces performing additional excavation to achieve desired geometry of the mining face [5].

Literature around the world points out that topic of drilling optimization is well-known, and analyzed sources agree that poor safety level of the operator is the main problem. Location of drilling rig operation in mining faces is the most dangerous zone in the mine. Probability of collapse of ceiling or singular pieces from the ceiling is very high. Hence, mining industry around the world pursues the direction of eliminating human from the exploitation front. Robotizing the drilling rig is currently the key direction of drilling modernization.

2.1. The main regimes of the drilling process

In analyzed case, when drilling occurs, diesel engine is turned off, and drill is powered from electrical grid in the mine. Electricity powers hydraulics, rotation, percussion and feeding systems, as well as movement of the tool. Dust remaining in the holes is removed during flushing and blowing the holes. Drilling cycle with percussion-rotation technique should include the following operations:

- **Tool positioning** – it is essential that frame is firmly pushed against the wall to avoid any sliding.
- **Pre-boring** – drilling head is pushed against the wall. Drill rotation and percussion are switched off. Pre-boring starts with low values of percussion and feeding pressures, and flushing enabled. When tool is deep enough in the wall, parameters are elevated up to nominal values. If there is a need, operator can correct the position of tool frame.
- **Drilling** - operator adjusts the pressures according to rock type. Some systems do it automatically. Flushing is responsible for overheating protection and allows for removing the rock dust in real time. It is achieved by keeping steady levels of water and air pressure. If a hole is drilled in delaminated or varying firmness rock, drill jam can occur. In some cases it can lead to drill head damage (e.g. in case of meeting porous material). There are mechanisms to protect from such situations, e.g. anti-jam system or cavity detection system. Such solution can automatically reduce feed speed when rotation pressure or oil flow in feed line increases rapidly.

- **Removing tool from drilled hole** – when desired depth of the hole is achieved, feed direction is change to the opposite retaining rotation and percussion at previous levels. Flushing is switched off and the hole is blown with air [13].

2.2. Identification of activities

Example of process record is presented in Figure 3.

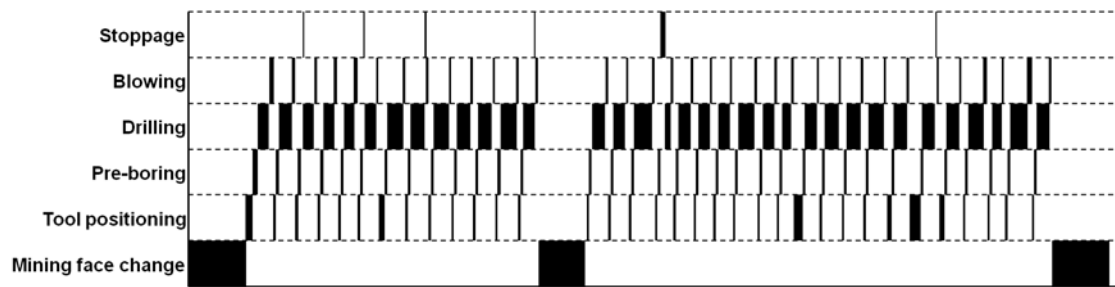


Figure 3. Gantt chart presenting drilling process

Currently the best way to control the drilling process is operational parameters monitoring, which, when preprocessed, enable identification of the main activities, and present the information about consistency of drilled holes according to drilling pattern, taking into consideration such parameters as holes depth, their count and geometry, as well as information about front change, geological conditions, detected anomalies and their causes. Engineers are currently facing the challenge of developing solution that will allow to improve main indicators of drilling process. Recognized drill control systems allow for continuous analysis of drilling conditions, and automated operational parameters setting. One of the most popular control systems is GOAD made by J.H. Fletcher & Co. System allows for testing drilling tool kinematics and monitoring of drilling parameters.

3. Development of algorithms for automation of drilling process

3.1. Targets

When analysing the structure of the drilling process it may be noticed that the whole process can be divided into two elements, whose robotization may be solved separately:

- automated tool positioning,
- automated drilling.

The first should be able to move the drilling head between planned locations of holes. At each location the drilling head should be positioned at desired coordinates and at the angle suitable for the hole to be drilled. After the hole is drilled, the head should be moved to the next location. The automated drilling itself should execute the drilling, it should allow the movement of the drilling head in one axis (along the drilled hole) with a control of a correct execution of the process: controlling the movement and drilling velocity, forces and torques as well as water and air pressure with respect to the type of the rock that is drilled.

In our research we focused on the tool positioning task. For that purpose, a laboratory test rig has been designed. Below we describe the design, capabilities and tests that has been done with this test rig.

3.2. A general algorithm of the drilling process

The general algorithm of a robotized drilling process may be concluded in the following steps:

Step 1: Positioning of the drill setup in front of the mining face,

- Step 2:** Identification of the mining face shape,
Step 3: Planning the drill pattern,
Step 4: Planning the manipulator motion (order of holes),
Step 5: Drilling plan execution.

In the first step, the manipulator is positioned in such a place that the whole mining face is in the working area of the manipulator, so the drilling head may reach all required positions. In the second step the dimensions and shape of the mining face is determined, for example with a use of a 3D laser scanning. Next, in the third step the drill pattern is fitted to the identified mining face: the number and location of the holes is determined. In the following step it can be found the order in which the holes are drilled is planned using an optimization process to obtain the most effective motion of the manipulator. In the last step the holes are drilled according to the predefined plan.

3.3. Development of the test rig

During the design of the test rig it was assumed that it will have a form of a portable laboratory setup to test some aspects of drilling and rock breaking tasks. Due to the small scale of the rig, it does not have a drilling head capable of drilling rocks. The test rig consists of an industrial manipulator, base structure and a stand with light and video modules mounts. The manipulator has six actuated axis and has a maximum working load of 5kg and reach of about 700mm. The base structure contains a mount for replaceable panels which simulate walls to be drilled. The test rig is presented in Figure 4. The robot is connected with an external PC computer via Ethernet interface and Wi-Fi router.

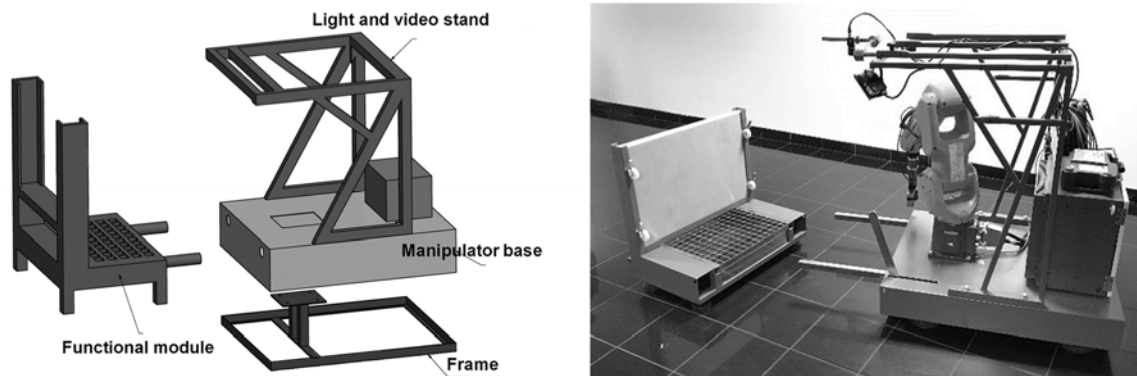


Figure 4. Developed test rig for tests of tool positioning in drilling process

Currently the setup allows test of steps 3, 4 and 5 of the general algorithm presented in section 3.2. It can be further developed to include also step 2.

3.4. Tests

The test rig allows two modes of operation: offline and online. In the offline mode the drilling pattern is transformed to a list of points which are to be reached by the manipulator and paths between those points. Exemplary drilling pattern, which is a list of position, orientation and depth of the holes, is presented in Figure 5.

| | A | B | C | D | E | F |
|---|-------|-------|-------|-----------|-----------|-----------|
| 1 | x[mm] | y[mm] | z[mm] | rot X [°] | rot Y [°] | rot Z [°] |
| 2 | 0 | 0 | 20 | 0 | 0 | 0 |
| 3 | -150 | 0 | 20 | 0 | -30 | 0 |
| 4 | 150 | 0 | 20 | 0 | 30 | 0 |
| 5 | 0 | -100 | 15 | -30 | 0 | 0 |

Figure 5. A drilling pattern: list of holes parameters

A specialized application allows visualization of the planned holes (Figure 6) and compiles the points and paths into a motion program for the manipulator. The program is then loaded to the manipulator controller and executed without additional feedback from a vision system. An example of the offline drilling is presented in Figure 7.

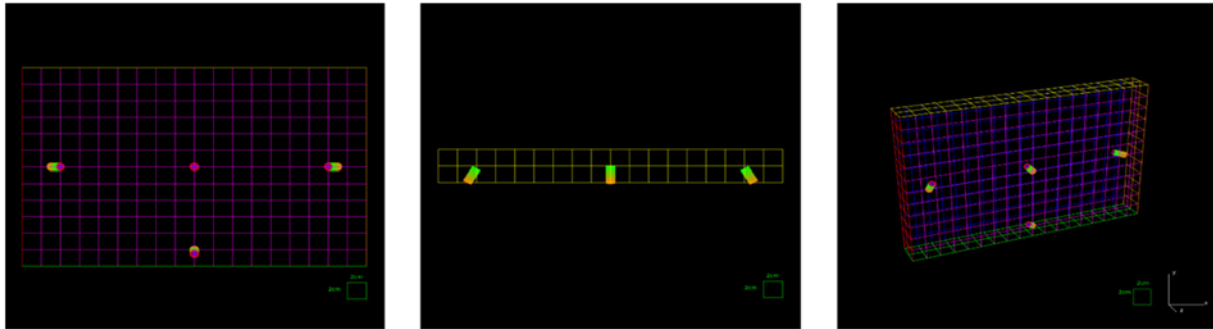


Figure 6. Visualization of the drilling pattern



Figure 7. Example of offline drilling

In the online mode, the drill pattern is presented on the mining face in form of the markers of various shapes. The manipulator controller does not receive a unique program for each mining face, instead it uses a video system to detect the markers. The drilling head is moved to the location corresponding to the position of the markers, and the shape of the marker indicates the angle of drilling and the depth of the hole. In the tests the markers were printed and attached to the wall (Figure 8), but they can also be projected to the wall using a laser light.

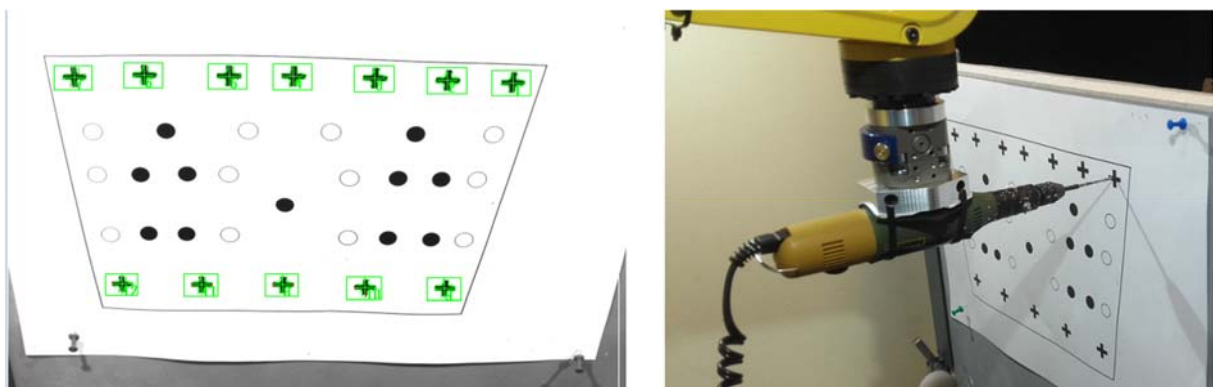


Figure 8. Example of online drilling: markers detection by the vision system and motion execution

Comparing the two modes, the offline mode assumes that the conditions during the drilling do not change and the whole program may be executed without modifications. The compilation of the program and loading it to the controller is an additional step that requires a connection between the robot and the external computer which plans the motion. An advantage of this approach is that all the parameters for each hole can be individually set. In the online mode, the manipulator executing the tool positioning and the drilling planner can be separate systems and do not need to communicate. In this mode when the manipulator finishes drilling each hole, it searches for a marker indicating the next hole to be drilled. It allows then an online modification of the drilling plan. However a drawback of this mode is a lower flexibility, as the vision system may recognize only a limited set of the markers and therefore the holes parameters must be chosen from a limited set.

4. Conclusions

A problem of automatic drilling system has been discussed in this paper. As drilling is performed in the most dangerous area in the mine, and it could be considered as repeatable process, it is proposed to use robotic system. Due to high cost for in situ research, a test rig has been proposed. A prototype has been designed. Several significant assumptions have been accepted. The process has been decomposed into sub-processes and each sub-process has been considered to be robotized/automated. Finally, algorithms for two key processes (positioning and drilling) have been proposed and implemented. For first problem two solutions are available (online/offline). Holes distribution is uploaded to robot controller or i.e. vision system recognized position and control the robot adaptively. So far, drilling is simplified (no force/torque measurement; length of hole is monitored by system). Future work is planned: modifications related both to measurement layer and control system will be proposed.

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