LESZEK KASPRZYCZAK
PAWEŁ SZWEJKOWSKI
MACIEJ CADER

Robotics in mining exemplified by Mobile Inspection Platform

The paper presents the Mobile Inspection Platform (MPI) – the innovative solution in the area of safety in underground coal mining. The robot is equipped with devices and sensors that allow the safe exploration and monitoring of these mine regions, that have environmental conditions which are potentially dangerous for a worker. The paper describes in details also the process and results of tests conducted in the Central Mines Rescue Station (CSRG).

Keywords: *mobile platform, safety, monitoring*

1. INTRODUCTION

The robotics of modern mines is a strategic issue due to the fact that deeper and deeper beds are exploited which are vulnerable to different hazards, particularly climatic hazards (higher temperature and humidity), eruptions and emissions of dangerous gases (methane, hydrogen sulphide), endogenous fires with accompanying emissions of carbon monoxide and dioxide, or eruptions of water and rocks [12]. For these reasons, people should work as far as possible from dangerous zones (extraction areas) and the most beneficial solution would be to apply remote control of the extraction and transport processes. Similarly, in the case of rescue operations, people should be replaced by robots equipped with sensors for measuring concentrations of dangerous gases and for determining climatic conditions. These robots should work as reconnaissance for rescue teams, giving them, in advance, information about the conditions in the excavation and providing better security for people. This necessity is recognized all over the world which is proved by many solutions of mining robots coming from different countries [1, 4, 5, 10]. Please note such robots as Groundhog, Wolvarine V-2 and Gemini-Scout from the USA, Numbat or robots made by Water Corporation from Australia. GMRI and MPI performed in Poland by institutes EMAG and PIAP and Telerescuer performed by international consortium. The Chinese company Tangshan Kaicheng Electronic makes robots for the hard coal mining industry. In addition, mines rescue stations want to have mining inspection robots as they are often forced to suspend a rescue operation due to extremely hard conditions in the rescue area [11,14] and the risk which is not acceptable for rescue teams.

This article features the achievements related to the project “Research and feasibility study of a model of an M1-category mobile inspection platform with electric drives designed for explosion-hazard zones”. The project consortium is formed by the Institute of Innovative Technologies EMAG and Industrial Research Institute for Automation and Measurements PIAP. The project was financed by the National Centre for Research and Development. The project result is a technology demonstrator called Mobile Inspection Platform (MPI).

The most important functionality of MPI is its ability to measure concentrations and parameters of the mine atmosphere permanently or at the operator’s demand. Then the measurement results are sent to a measurement-control panel where they are archived together with video recording from cameras that work in visible and infrared bands. MPI is exploited in explosive zones and zones with group-I explosion hazards. Therefore, from the very beginning, the robot was designed to comply with the requirements of the 94/9/EC (ATEX) directive, 2006/42/EC (MD) machinery directive and 2004/108/EC (EMC) directive. The robot was also designed to overcome different obstacles, such as debris, water, mud, or tracks of floor mining railways.

2. MOBILE INSPECTION PLATFORM MPI

Mobile Inspection Platform (MPI) is a technology demonstrator developed by the EMAG-PIAP consortium. The division of work between the two institutes was based on their competence ranges. The PIAP Institute worked out mechanical assemblies of the platform (flame-proof enclosures working as platform enclosures, pressurized enclosure of the TV tower, unwinder of the optical fibre, pipe rack, enclosure for intrinsically safe electronic elements) and selected suitable wheels (rims and tyres), drive blocks made of brushless DC motors, angle helical gear units, and brakes (Fig. 1). The EMAG Institute developed electronic and programmable electronic subassemblies (measurement systems, visual systems, transmission systems, communication controllers, motor controllers, electrical batteries, and casings for particular subassemblies and, where ncecessary, software for measurement, control, communication, and archiving). Detailed technical solutions are included in unpublished documentation from particular project stages prepared by the institutes. Functional assumptions and concepts of the MPI technical solutions were described in [13]. Further in the article, the authors presented the project results and pointed at standards whose requirements the presented platform complies with.

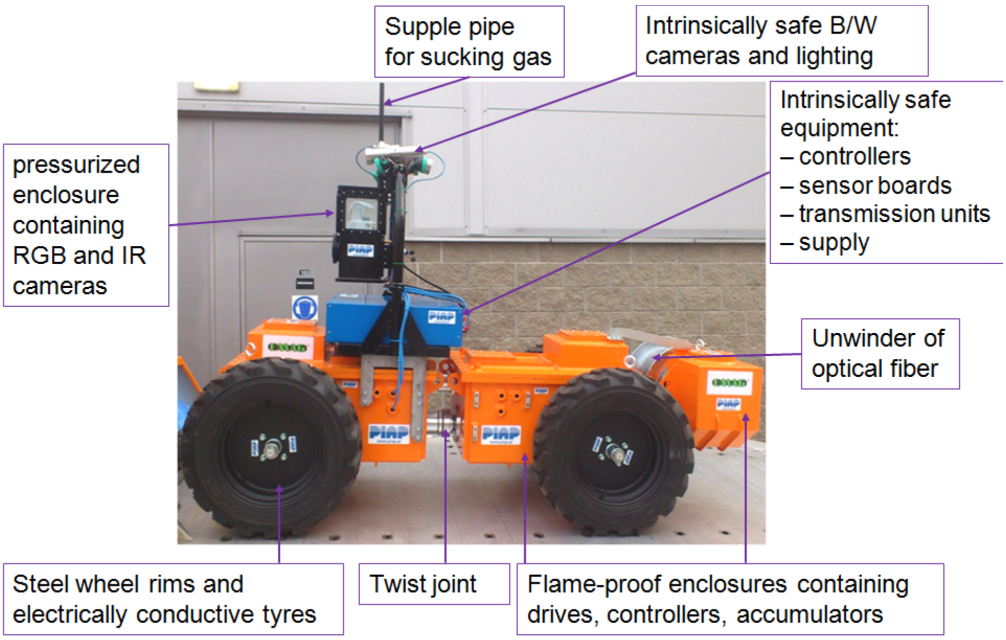

Fig. 1. Mobile Inspection Platform MPI

MPI is characterised by the following parameters: weight about 1100 kg, maximal velocity 0.7 m/s, distance range 1000 m in the depth of excavation, dimensions: length 240 cm, width 115 cm, hight 180 cm, supply 42 VDC. It is not possible to move the robot through 80 cm diameter hole in dams.

3. DRIVE AND FLAME-PROOF ENCLOSURES OF MPI

MPI has four wheels with tyres, each driven by an independent drive block. The PIAP Institute selected steel rims and tyres which conduct electricity in order to prevent the effects of electrostatic discharges. The drive block is composed of a brushless DC motor, angle helical gear unit, brake, and motor controller. Each drive has its own lithium-polymer battery. The motor is made with the use of the increased explosion-proof safety technology “e” in compliance with EN 60079-7, while the gear unit and the brake are protected by liquid immersion in compliance with EN 60079-6. Electronic printed circuit boards of motor controllers and batteries are encapsulated according to EN 60079-18, while the connections of the motor controllers and the batteries cells comply with the requirements of the increased safety “e”. The drives were placed in flame-proof enclosures "d" in compliance with EN 60079-1. Such solutions are ensured by double explosion-proof safety which, in the light of the EN 50303 standard, enables to achieve the M1 category, meaning that the platform can work permanently in the presence of group-I explosive gases and/or coal dust.

An emergency stop of the machine is performed by two emergency switches, one placed on the front and the other on the rear cart of MPI. The switches, together with relays and contractors, are responsible for the emergency stop safety function with the Peformance Level PLc [2] according to EN ISO 13849. Theoretical calculations of electromechanic drives are presented in [3].

4. METROLOGICAL SYSTEM OF MPI

Mobile Inspection Platform is equipped with two identical modules of gas meters. Infrared sensors were used to measure concentrations of carbon dioxide and methane in a low and high range, while electrochemical sensors for measuring concentrations of oxygene and carbon monoxide. Methane is measured in the range of 0…100%, carbon dioxide 0…5%, carbon monoxide 0…1%, oxygene 0…25%, temperature -40…+120°C, and relative humidity 0…100%. Due to the fact that the humidity in an isolated zone is usually very high (close to 100%), a drier system was developed which dries the gas mixture before it is introduced to the sensors. Then the mixture goes to the measurement chamber which has gas concentration sensors and diagnostic sensors monitoring proper work of the system. The internal temperature sensor enables to compensate the impact of temperature and informs whether the temperature threshold of gas measurement sensors was exceeded. The humidity sensor, in turn, gives information about the quality of the drying process in the drier. The flow sensor informs whether the pump sucks the air efficiently. The external temperature and humidity sensors, placed outside the measurement chamber, provide data about climatic conditions in the excavation surrounding MPI.

In order to increase the safety of rescue teams, a redundant solution of gas meters was applied in MPI. It is difficult to rely on the readings of a single meter, only. Here it is important to note the measurements of the poisonous carbon monoxide and explosive methane. In the MPI measurement system the two-out-of-two voting (according to EN 61508) was used. The measurement results in both channels have to comply with each other in the range of the adopted tolerance, so that the measurement could be recognized as plausible. Therefore, before the decision is made to send the rescue team to a dangerous zone, the measurement results in both channels have to show permissible values of dangerous gases concentrations. If one channel shows a safe value and the other an unsafe one, MPI has to be withdrawn and both modules of the sensors have to be calibrated.

5. VISUAL SYSTEM OF MPI

The visual system of MPI is composed of four cameras and lighting. Two monochrome cameras (black and white), produced by EMAG, are intrinsically safe and comply with the "ia" category from EN 60079-11. These cameras do not have drives. One of them is directed towards the front, the other towards the rear part of the robot. A colour high-resolution camera is placed in a pressurized "px" enclosure according to EN 60079-2. Thanks to its drive, this camera can be moved in the vertical and horizontal planes. Below the colour camera, there is a thermal camera with no drive. The TV tower is equipped with windows made of soda-lime glass (for the colour camera) and germanium glass (for the thermal camera).

Inside the TV tower, the pressure is higher in order to prevent the external gas mixture from getting inside. There is an intrinsically safe device in the enclosure. The device monitors the difference between the inside and outside pressure. If the enclosure gets unsealed, the power provided to the cameras will be cut off. The safety device has the SIL2 Safety Integrity Level in compliance with EN 50495 and a "px" explosion-proof structure, which both enable to achieve the M1 category for this assembly of the robot.

There are four lamps on the pipe frame – two are directed towards the front and two towards the rear part of the vehicle. The lamps are switched off remotely by the operator. Casings from typical mining laps were used but they were equipped with stronger LEDs and supplied from intrinsic safe batteries.

6. TRANSMISSION SYSTEM OF MPI

The operator sends control commands from the measurement and control panel (computer with higher immunity to environmental factors – IP54, resistant to shocks and vibrations) equipped with an advanced joystick. There are two options of remote communication with MPI: Wi-Fi and optical fibre [9]. When MPI is moving towards the rescue operation place, Wi-Fi communication is used. When the robot is in the examined excavation, a non-infammabe optical fibre is employed. The optical fibre is unwound from the unwinder.

The control commands are received by the robot in the TCP computer and then distributed to particular microprocessor controllers. The commands responsible for the movements of the robot are sent from the TCP computer, through the Main Processer to the Superordinate Motor Controller, and then to particular controllers of brushless DC motors. The commands to trigger the measurements are sent from TCP, through the Main Processer to two sensors modules. The Main Processor is also responsible for switching on lamps and serves as a communication node for data streams from monochrome cameras. Data streams from the colour camera and the thermal one are sent directly through TCP and the optical fibre to the operator's panel. The listed transmission systems had been developed according to the intrinsically safe "ia" technique and were placed in a blue IP54 enclosure fixed to the front flame-proof enclosure of the robot. Apart from that, in the enclosure there are four intrinsically safe batteries to supply power to separated electrical circuits.

7. FUNCTIONAL AND TRACTION TESTS OF MPI BY CSRG S.A.

Functional tests of the platform were conducted by the Central Mines Rescue Station (CSRG). The tests were performed in training excavations on the CSRG premises. Figure 2 shows the robot entering a training excavation. Figure 3 features the view of the control and measurement software of the operator's panel.

Fig. 2. MPI before entering a training excavation of CSRG [7]

Please find below the English version of the CSRG's report, section 5: Final assessment of the test results [7]:

The functional tests of the Mobile Inspection Platform (MPI) model allow to state the following:

1. the assumed properties and qualities of MPI make it possible that, in the identified situations, the rescuers can be replaced by MPI during the inspection of underground excavations and during measurements of environmental parameters, particularly in explosive or unbreathable atmospheres.
2. the mobile part of the model meets the assumed properties and characteristics (…). The video captured by the cameras in the conditions of no stable lighting in the excavation was of good quality. This allows efficient control of MPI in the necessity to observe the itinerary by the remote operator.
3. the work of the operator's station (panel and power supply) was correct. Wireless communication (along a section of about 25 m) in the software application of the device worked unfailingly. The platform control in the device prototype, administered by the operator by means of a joystick, allowed to control the directions of the platform and the colour camera in an efficient way. According to the assumed assessment level of functional tests, the same can be said about the work of the measuring application (the tests did not cover metrological assessment).

Fig. 3. View of control and measurement software of MPI [7]

Traction tests were conducted by CSRG's rescuers in the underground of the Królowa Luiza Mine. It was estimated that the robot covered a distance of about 250 m there, passing through a ramp with the inclination of about 30°, a relatively loose ground of corridors (loose stones where the wheels of the vehicle surged sometimes), railway tracks, rail points, and obstacles that are typical of the mine infrastructure (necessity to go round the mine equipment and devices, stored materials, carriages on tracks, powered roof supports, etc. – Fig. 4). During the tests the team tested also the work of sensor sets and cameras. The functionality of the mentioned assemblies was satisfactory. The traction tests were completed successfully.

Fig. 4. MPI copes with obstacles in the mine infrastructure [14]

8. CONCLUSIONS

The number of mining robots solutions has been increasing year after year. This situation proves that there is quite a big market niche for such products. A Chinese company Tangshan Kaicheng Electronic estimates its production capabilities at 1,800 mining robots annually [10]. The market for mining robots is sure to be an absorptive one due to the fact that the rescue operations headquarters do not want to risk the lives of rescuers during operations in explosion-hazard and explosive zones. Police and military sappers have been equipped with adequate robots for explosives desactivation for years. Therefore, it is not an exaggeration to say, that similar solutions will be at disposal of mining rescuers in the next few years.

However, contrary to the sappers' robots, the mining robots, apart from functional requirements, have to comply with the requirements imposed by legal regulations, such as European directives, including the most important ATEX, EMC and MD directives. Each solution has to prove its compliance with the above directives. Recognized techniques to make explosion-proof solutions, such as flame-proof enclosures, pressurized enclosures and encapsulation, make the devices heavier and bigger. This, in turn, leads to worse functionality of the vehicle. Therefore it is important to use an optimal design method in order to fulfil necessary explosion-proof requirements on one hand and to keep the functionality of the robot on the other hand.

From the very beginning, Mobile Inspection Platform was developed based on the requirements of standards harmonized with proper directives. This procedure enabled to optimize the development of assemblies. However, as particular assemblies were manufactured by two institutes (EMAG and PIAP) which complemented each other in the project, some solutions were made a priori, i.e. those concerning the weight and shape of the robot assemblies. So there is a space to optimize the robot size, weight, parameters, and assemblies location.

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LESZEK KASPRZYCZAK, PAWEŁ SZWEJKOWSKI
Institute of Innovative Technologies EMAG
l.kasprzyczak@ibemag.pl; p.szwejkowski@ibemag.pl

MACIEJ CADER
Industrial Research Institute for Automation and Measurements
mcader@piap.pl

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