GOSPODARKA SUROWCAMI MINERALNYMI
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ANDREW JAROSZ*

Development of inspection system for evaluation of Ore-passes at Grasberg Mine, PT Freeport, Indonesia

Introduction

Mine ore passes are crucial elements of ore flow system and their failure may have significant adverse impacts on performance and productivity of a mine. In most cases there is no direct human access to these underground structures and remote techniques must be used to perform inspections and surveys. The collected visual and metric data can provide the necessary information required for assessment of stability and safety, as well as, for the planning of eventual reconstruction (Logan et al. 1993; Szwedzicki, Cooper 2008) of the damaged ore passes. In 1999 the Western Australian School of Mines (WASM) conducted industrial survey regarding the need for development of a tool, which can allow inspection and survey of vertical openings and shafts in the underground mining environment. The positive response led to initiation of a research project aiming at the development of Vertical Opening Inspection System (VOIS), a platform able to collect and integrate visual and metric data representing the status of mining ore-passes.

Up-to-date, most of inspection systems utilised a sensing pod suspended on a cable deployed from a winch. The suspended pod was usually equipped with illumination sources, video cameras and a recording device. In most cases operators were not able to control the pod's stability and the data recording process. In some cases, the analogue video signal was transmitted over data lines imbedded into the steel suspension cable to a control unit located in the proximity of a winch. Stabilisation of a pod with cameras was the main problem of the existing systems. They did not have any surveying capabilities, either, that allow for collection of metric data.

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* Curtin University of Technology, Western Australian School of Mines, Kalgoorlie, Western Australia.

The vertical opening inspection system (VOIS), which is under development at WASM, provides both, the inspection and surveying capabilities. The unique gyro system provides rotational stabilisation of the pod and allows for significant increase of data quality. The unit's design is based on standard, off-the-shelf and low cost, components merged with smart programming and advanced communication systems. When lowered along a shaft or ore pass the tool acquires digital images, utilising its forward and side view cameras, and combines them with pod motion data provided by the on-board inertial motion unit (IMU). An extension of the inspection pod with a laser scanner allows collection of metric data. All data is transmitted to the control station. The inspection data are then processed with the use of the specially developed software to produce results that can easily be accepted by the common mine design software packages. The collected information is compared with previous surveys and any changes are detected and analysed.

The project went through many stages of development over the last eight years. Initially the technical developments were split between WASM Kalgoorlie, CSIRO Floreat and CSIRO Brisbane, Pinjarra Hills, which produced the first prototype in 2005. The need for modifications to allow inspection of the ore passes at the Grasberg Mine, PT Freeport Indonesia (PTFI), have given the new momentum to this project. It has allowed for resolution of issues with the initial prototype and for further extension of its capabilities. The PTFI requirements included extended range (min. 650 m) and improved stability of the pod. The first visual inspection of the Grasberg's ore passes was carried out in May 2006. This initial inspection unveiled few more technical issues that included the need for further improvement of video and pod stabilisation systems. Incorporating a profile laser scanner into the design have allowed for collection of metric data. It should be noted that the period 2006–2007, was characterised by the intensive research and development activities, which have led, in May 2007, to successful inspections and surveys of Grasberg ore passes, one of the deepest in the world (~650 m).

1. System Components

Conceptually the system is quite simple. A sensing platform is lowered down a vertical shaft or ore pass on a cable to collect video, positional and metric data. The whole system is made of three major components: 1) the deployment system, 2) the data sensing system and 3) the data collection system. The deployment system consists of a winch and a hydraulic crane mounted to a modified light vehicle (LV). The sensing platform contains: power supply, communication systems, motion sensor (IMU), stabilisation system (gyro), video system (cameras) and a rotating distance ranging device (laser profiler). A portable computer is used for data collection.

1.1. Deployment System

A commercial off-the-shelf winch, with specifications to support the mass of the pod of about 50 kg, was selected as the main component of the deployment system. The winch was

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modified to include 1) an intelligent microprocessor controlled counter for indication of depth, 2) slip rings to allow electrical and data connections to the rotating cable drum, 3) data communication system, 4) control pendant for winch drive. One kilometre of four-conductor steel armoured wire line was spooled onto the winch with a cable drum total capacity of 2 km.

A commercial hydraulic crane (Kevrek 700) was also acquired for pod positioning during deployment. The winch and crane were mounted on a modified Toyota C100 4WD vehicle, to enable access to remote mining operations. Figure 1 shows a photograph of the survey vehicle with crane, winch and pod. A diagram presenting the winch components is shown in Figure 2.

Fig. 1. VOIS and its deployment system mounted on LV

Rys. 1. VOIS i system jego stosowania oparty na niskim napięciu

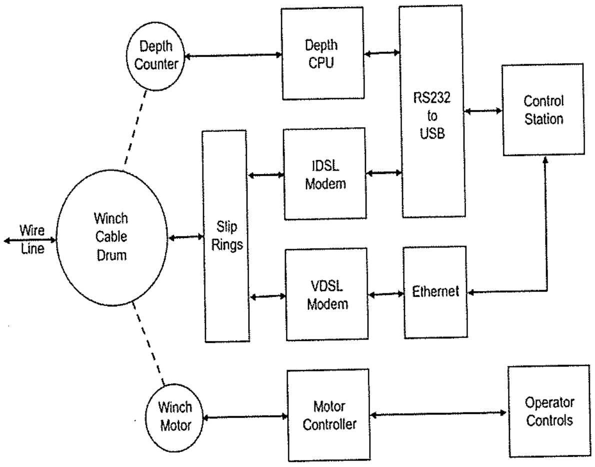

Fig. 2. Block diagram of winch components

Rys. 2. Schemat blokowy elementów wyciągarki

1.2. Pod Components

The pod system is divided into four major components, namely:

1. Data Communications and Power Control.
2. Gyro Stabilisation and Motion Data Collection System.
3. Digital Video Capture and Control.
4. Laser Scan Data Capture and Control.

Each pod component utilises several embedded sub-processors to provide distributed control of the various functions as shown in Figure 3. The distributed processing allowed rapid development of the pod component systems independent of one another. The standardised communications links (Fire Wire, RS232, USB, and Ethernet) were leveraged to link the sub processors together into a fully functional system.

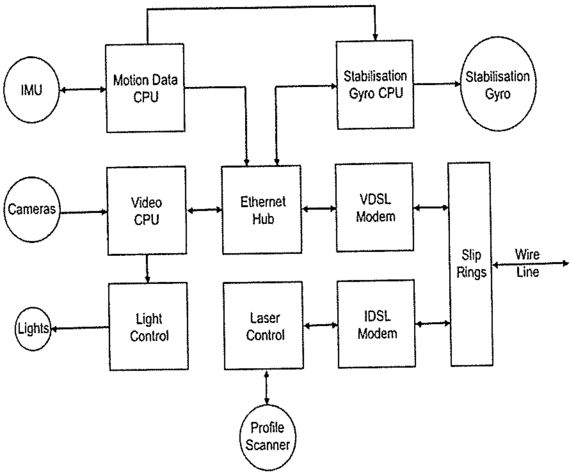

Fig. 3. Block diagram of pod's components

Rys. 3. Schemat blokowy elementów gondoli

The presented diagram was implemented in the final design, integration and layout of video and survey sub-systems.

2. System Design Issues

2.1. Pod stabilisation

The testing of the initial system disclosed that the pod was undergoing significant rotational motion when it was raised or lowered into a shaft. This issue was initially addressed by replacing the existing Kevlar cable with polyurethane coating with a counter wound sheath wire line cable. This replacement significantly reduced the amount of rotation, but did not stop it entirely. Additional means of stabilisation was required to further reduce the rotation of the pod.

The two methods were considered:

1. Simple pulley arrangement to mechanically maintain a fixed orientation.
2. Inertial gyro system with active control linked to a reference gyro (IMU) and decoupling of the pod from the suspension cable using a rotating swivel at the top of the pod.

If a fixed orientation could be maintained with a simple pulley system this would remove the need to measure the orientation of the pod as it was lowered into a shaft. Lab and limited depth field testing of pulley based stabilisation system yielded promising results by maintaining the pod in a fixed orientation as it was raised and lowered down the shaft, as shown in Figure 4.

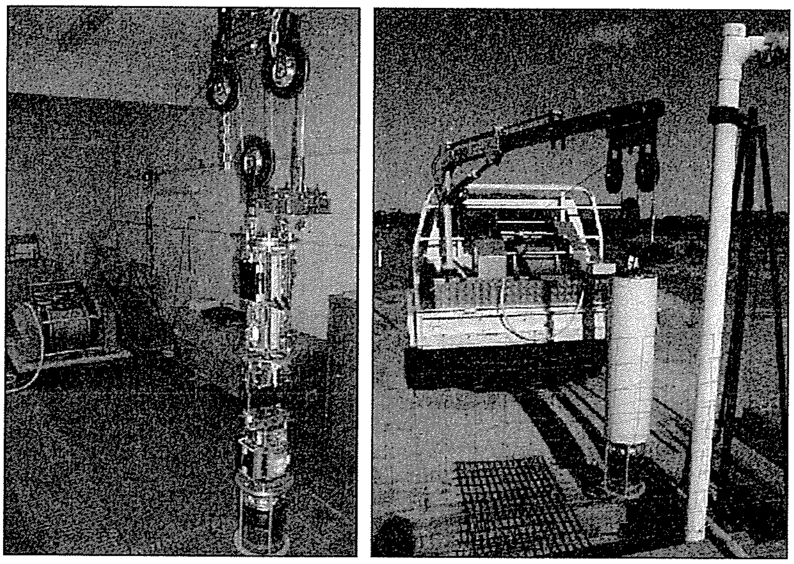

Fig. 4. Lab and field tests of pulley based stabiliser

Rys. 4. Testy laboratoryjne i terenowe stabilizatora działającego za pomocą koła pasowego

Further testing in the field showed that the pulley system was able to maintain pod's fixed orientation only to the depth of 60 meters and the system was abandoned. Focus was shifted to the development of active gyro-based stabilisation.

The reference azimuth data provided by IMU were processed and fed to the inertial gyro, to enable active stabilisation of the pod (Figure 5 – right). To further improve pod rotational stability a rotating coupling was constructed to allow unwinding of the suspension cable and to not impart its torsion force on the pod causing axial rotation. The coupling also required a slip ring assembly to allow the electrical connections between pod and cable, show in Figure 5 (left).

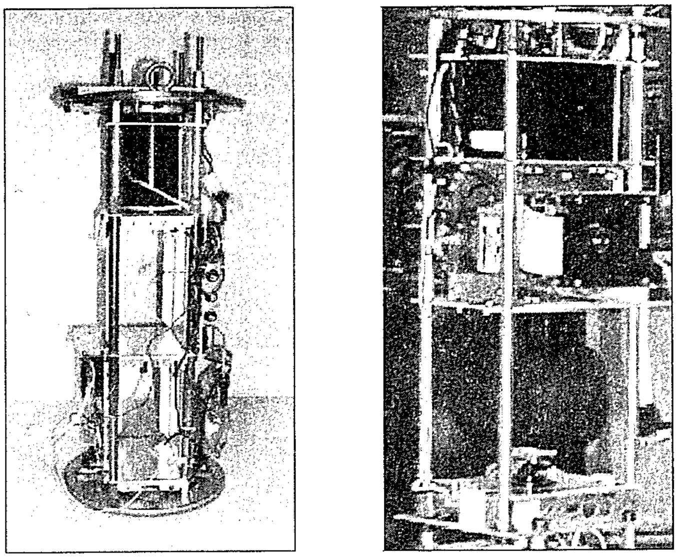

Fig. 5. Rotating swivel (left) and active gyro-stabiliser (right)

Rys. 5. Obracający się krętlik (po lewej) oraz aktywny żyro-stabilizator (po prawej)

2.2. Integration of Laser Scanner

During early stage of the project, different methods of determining distances electronically were reviewed to form the basis of a profile-scanning component.

These methods included:

1. Acoustic pulse echo distance measurement (Sonar).
2. RF pulse echo distance measurement (Microwave and mm Radar).
3. Optical parallax distance measurement (Video Imaging).
4. Laser pulse echo distance measurement or TOF (Time of Flight).

It was decided to use an Electronic Distance Measurement (EDM) device that will sweep through 360°, in the horizontal plane, as the basis of a profile-scanning component.

A review of available EDMs was performed to assess its suitability of meeting profile-scanning requirements of the system (Fröhlich, Mettenleiter 2004; Staiger 2003) A device based on the time of flight (TOF) laser distance measurement method was chosen. The maturity of the technology and market availability contributed to this decision. During the early stages of the project, several commercial TOF laser profile scanners were assessed, but all had mechanical limitations and were unable to obtain an entire 360° profile. Faced with this prospect a readily available TOF laser rangefinder from Acuity Research (4000-LIR), with coaxial optics, was selected as the base for the in-house development of a laser profiler. However, as a part of the design cycle a search and review of OEM product availability was conducted periodically during the project development. During the final stage of construction of the in-house designed laser profile scanner a SICK OEM-LD scanner was located through the Internet search. The commercial SICK OEM scanner shared similar design ideas as the implemented in the WASM design, such as:

1. Sealed and compact construction.
2. Full circle (360°) scanning capability.
3. Coaxially mounted rotating optics and mirror assembly driven by a frameless DC motor.
4. Optical encoder to determine angular position of the mirror.

Although that the in-house laser profile scanner was nearing completion, further development ceased in favour of obtaining and implementing the SICK LD-OEM scanner. As the SICK LD-OEM model came as a complete unit it was simply "bolted on" to the bottom plate of the pod.

The modifications that were required to the head of VOIS pod to accommodate the LD-OEM laser scanner included:

1. Removal of the halogen front lights and the forward camera assembly.
2. Development and installation of new front LED illumination.
3. Modification of the forward camera to allow its mounting at the side of the laser.
4. Extension of the Perspex cover and the metal guard.

The original camera head and the modified camera head assembly with integrated SICK LD-OEM laser profile scanner are shown in Figure 6. The details of the rotating laser cap, LED front illumination and forward view camera are shown in Figure 7.

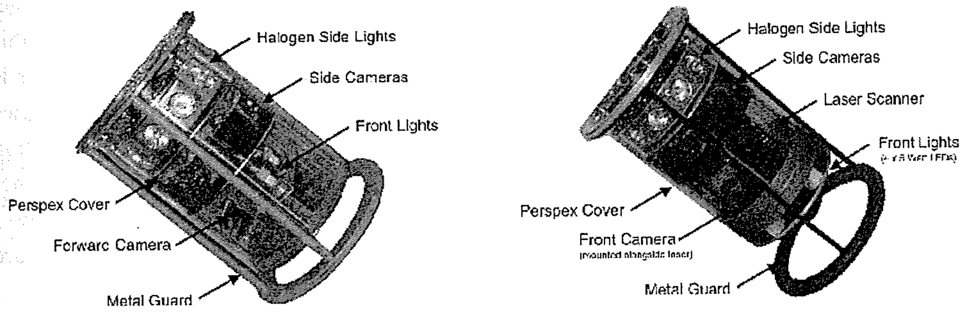

Fig. 6. Original (left) and modified (right) head of the pod

Rys. 6. Oryginalna (po lewej) oraz zmodyfikowana (po prawej) głowica

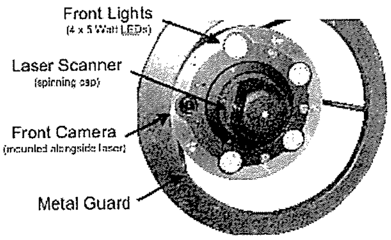

Fig. 7. Modified pod's head (front details)

Rys. 7. Zmodyfikowana głowica gondoli (szczegóły przedniej części)

2.3. Data processing and transmission

The system involves collection of data from the following devices:

1. SICK LD-OEM Laser – scanner profile data.
2. Winch – depth data.
3. IMU – orientation data (gyro azimuth).
4. Cameras – time of video frame capture.

The proper data synchronisation was the essential element of the design. The measurements to be accurately correlated were: time, depth, azimuth, and laser profile. Data exchange is bi-directional, between the surface control computer and the VOIS' pod hardware. To ensure correlation of individual data measurements, each sensing device has to respond to a data request in a predictable latency time. To achieve the required data synchronisation the original data communication system was replaced with a high speed VDSL. This provided a 4.3 Mbit/s communication circuit over the winch wire line and presented the "end-to-end" standard Ethernet connection, in the pod and at the surface computer. However, Ethernet in it basic form is a non-deterministic data transport, as it uses a data circuit access method: Carrier Sense Multiple Access with Collision Detection (CSMA/CD). This non-deterministic nature of Ethernet manifested itself when the video channels were running simultaneously and an RS-232 data channel for the laser was transmitted over the Ethernet circuit. The data from the laser scanner was not able to get through within an acceptable time window rendering them un-useable. To resolve this problem a separate data circuit was implemented using another DSL variant, iDSL, which is an implementation of ISDN (Integrated Services Digital Network). ISDN design specifies a synchronous deterministic data circuit, which removes the timing issues for the collection of laser profile data. This secondary circuit was wired, connecting the laser profile scanner data port directly to the surface data collection computer. With the laser scanner data port appearing as a locally connected device, the timing issue was shifted into the software domain.

The depth data also need to be collected with deterministic timing. This required the design, assembly and programming of an independent depth control processor directly mounted onto the winch. The depth processor was programmed with two tasks, specifically:

1. Read optical encoder mechanically coupled to the winch wire, store value, and calculate depth in meters.
2. Communicate with the control computer software over RS232 serial interface.

The addition of the depth processor also shifted the control of timing into the software domain. Control software for the laser and winch was written in Visual Basic 5.0 to aid in rapid development. Serial device drivers were written to communicate with the laser and the winch taking into account the timing requirements. A control process was coded with a simple graphical control interface to visually display the winch, IMU and laser data, as shown in Figure 8. The control code for the laser and the winch was rigorously tested in the lab environment and a test shaft.

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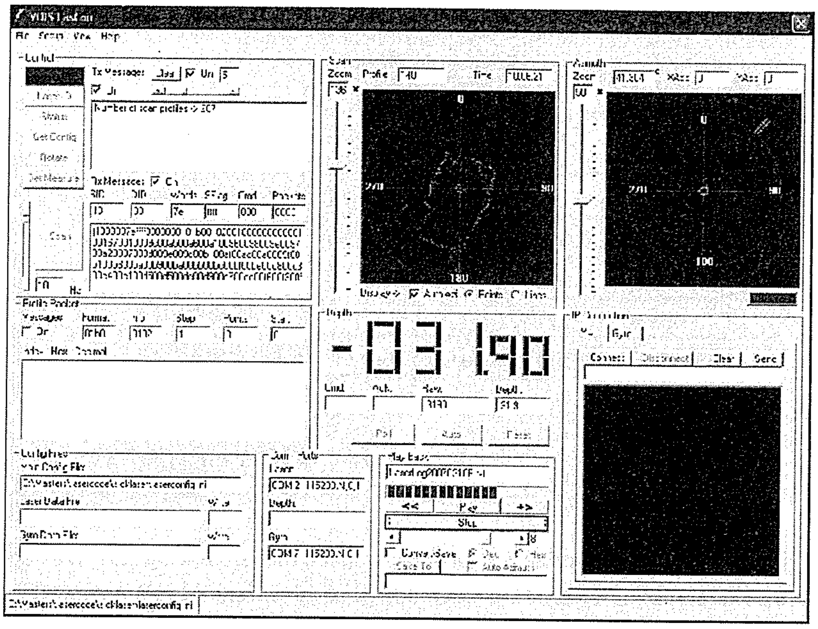

Fig. 8. GUI of laser control and display software

Rys. 8. Graficzny Interfejs Użytkownika sterowania laserowego oraz oprogramowanie obrazowania

3. Ore pass inspection at Grasberg Mine

After successful completion of field test in Kalgoorlie and at one of WA underground mines the equipment (winch and pod) was shipped to Grasberg Mine in Irian Jaya (West Papua), Indonesia. The plan included inspection and survey of four (4) active ore passes. The schematics of the ore pass system at its characteristics are presented in Figure 9 and Table 1.

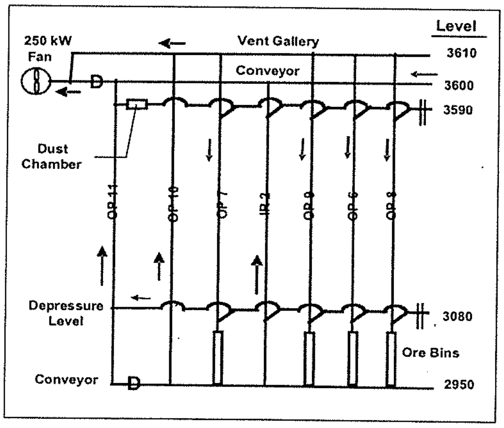

Fig. 9. Schematics of Grasberg ore-pass system

Rys. 9. Schemat systemu wyrobisk rud kopalni Grasberg Mine

TABLE 1

Ore pass specifications

TABELA 1

Warunki techniczne wyrobisk rud

Vertical structure	Depth	Diameter	Ore bin height	Ore bin diameter
OP6	650 m	2.1 m (widened to 4.5 m)	100 m	10 m
OP7	650 m	2.1 m (widened to 4.5 m)	100 m	10 m
OP8	650 m	3.1 m	100 m	10 m
OP9	650 m	3.1 m (widened to 5.5 m)	100 m	10 m
VR11	650 m	3.1 m		
VR10	660 m	4.1 m		
IR	660 m	2.1 m		

The PTFI designed and manufactured a boom and a winch mounting plate for deployment of the VOIS. The complete system had been designed to fit into a LHD bucket (Figure 10). The pod was deployed trough the open door of ore pass hopper using a "tag" line to pull it up against the bottom of the boom. When inserted it was lowered down. Once the pod was deployed the LHD bucket was lowered to a stable position with the ore pass door left open. The ore pass survey required that the pod "starting" position and orientation be known at the beginning of the survey. This information was critical, so the scan data could be correctly referenced to the mine's coordinate system. Reflective tape was attached to the wire line to provide a position of the first reference mark (A). A laser pointer, fitted to the top of the pod, projected laser ray onto the ore pass wall, which provided the second orientation mark (B), as shown in Figure 10.

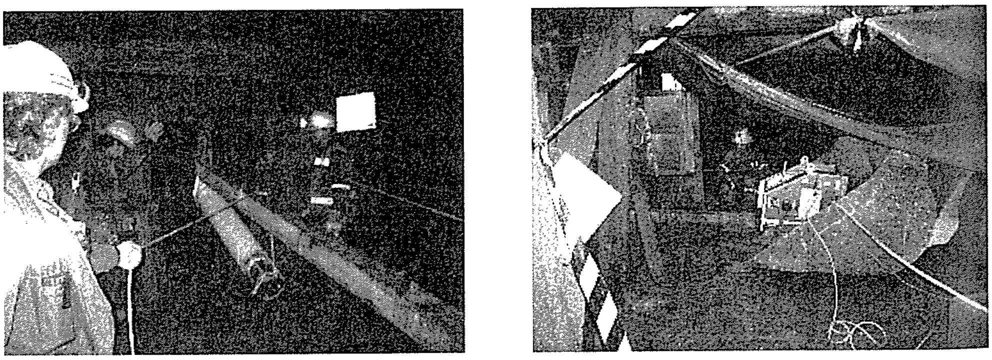

Fig. 10. VOIS deployment system

Rys. 10. Stosowanie systemu VOIS

At the same time instant, when the survey "pickup" of the pod orientation mark was taken, the pod reference gyro (IMU) and depth counter were set to "zero", so that data

TABLE 1

TABELA 1

	Ore bin diameter
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	10 m
	10 m
	10 m

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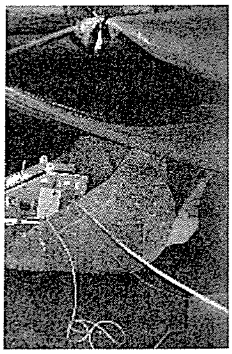

›rientation mark was
"zero", so that data

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collected from the IMU and depth counter could be referenced to the mine coordinate system. The positions of pod's "marks" (A and B) were calculated using the positions of known survey stations located in the proximity of ore pass access area.

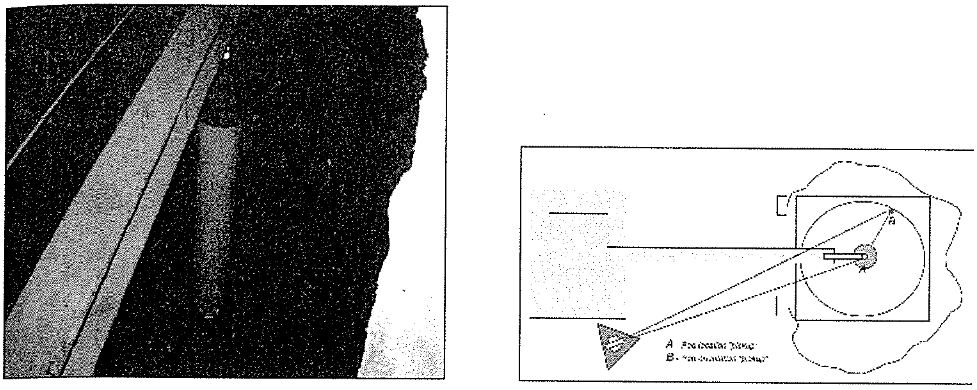

Fig. 11. Pod's location and orientation marks

Rys. 11. Oznaczenia położenia oraz kierunku ustawienia gondoli

4. Inspection and survey results

During the ore-pass surveys the control computer collected the following datasets:

1. Sets of images produced by each of the side looking cameras.
2. Cable payout data starting from the top of an ore-pass (from the initial position of the pod defined by laser mark B).
3. Pod's orientation and acceleration data (also referred to the initial position of the pod).
4. Laser data in the form of radial distances measured to ore pass walls, every one-degree for each horizontal scan.

The metric information, e.g. the cable payout, the pod orientation and the radial distances measured by a scanning laser were stored initially as the two text files: GyroLog<project>.txt and LaserLog<project>.txt in the controlling computer. These files stored the measured data as comma delimited values in line records The raw data contained in the initial files are converted, using the conversion facility of the Laser Control and Display program, and stored as a single survey results file: LaserConvert<project>.txt as comma delimited values in line records. The data stored in the "LaserConvert" file required further processing to be usable by general mine design packages such as: Vulcan3D, Surpac Vision or Datamine Studio. The processing have led to calculation of real world coordinates of the surveyed walls and storage of this information in a form of survey strings representing horizontal scans of these walls (Figure 12). Of many possible file formats, the Surpac string format was selected as the format of choice. The Surpac strings are stored as an ASCII text file that is characterised by simple and clean structure.

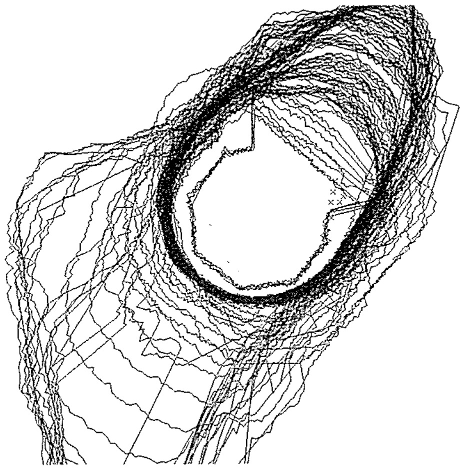

Fig. 12. Plan view of string representing surveyed ore-pass

Rys. 12. Widok planu badanych wyrobisk rudy przedstawiających kolumnę

The specialised data processing software "vois2surpac" was developed that allows calculation and conversion of pod orientation, cable payout and measured laser distances into the Surpac string format. The Surpac string files can easily be imported to other general mine design packages. Then, the processing capabilities of these packages are used to further manipulate the survey results into required formats e.g. wire frames, solids, cross-sections etc.

One of the main objectives of this project was to provide a tool for comparative analysis of ore pass wear and its wall failure over the time. To achieve this objective consecutive surveys of ore pass and comparative analysis of survey data are required. This analysis may involve the following activities: 1) Building a solid representing initial state of an ore pass, 2) Building a solid representing current state of an ore pass and 3) Performing operation of solid subtraction to determine changes between the initial and current states of ore pass.

Most mine design packages have capabilities to perform the Boolean operations on solids that allow for solid subtraction. The Maptek Vulcan3D, the mine design software used at Grasberg Mine, has also such capability and was used to carry out the ore-pass analyses.

4.1. Initial model of ore pass

Due to lack of available technology the Grasberg Mine ore passes were not surveyed immediately after their construction. The available information relates only to the design parameters like depth and diameter of the ore passes and size of the ore bins. It was summarised in Table 1 presented previously. To model the initial state of ore passes the information from could be utilised, however, additional information related to their position at the top and at the bottom was required. The position of the ore pass collar was derived from the existing mining plans at the level 3600. It was established as a centroid of the polygon ss

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representing ore pass access at this level. The arrangement leading to this determination is presented in Figure 13 (left).

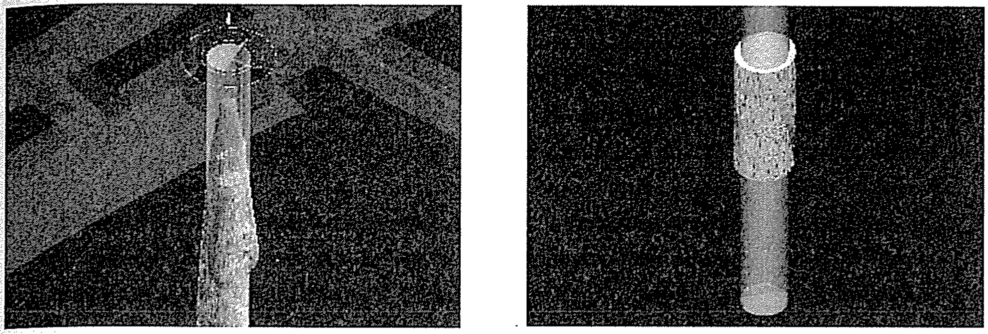


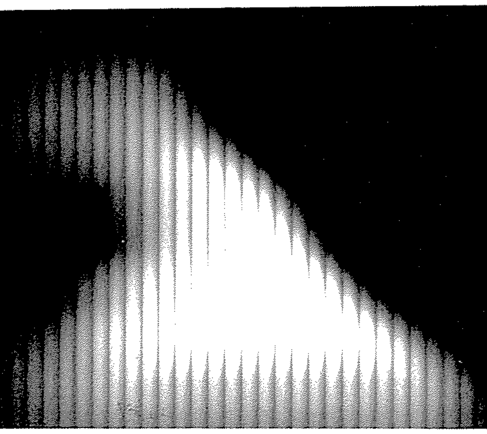
Fig. 13. Estimated top (left) and bottom (right) positions of ore pass as constructed

Rys. 13. Szacowane górne (lewa strona) i dolne (prawa strona) pozycje skonstruowanego wyrobiska rudy

The performed surveys proved that the ore bins at level 2950 were not concentric with the connecting ore passes above and they can not be used to locate the bottom section of the ore passes, as built. However, it was noticed that the bottom sections of ore passes were circular in shape, suggesting an even wear around its perimeters. As a result, a centroid, determined from triangulation representing current state of the ore pass walls, can well represent its initial (as built) position, Figure 13 (right). Utilising the top and bottom positions, design diameters and assuming straight construction, models of the initial ore passes were developed. These models were later used for assessment of ore passes wear and over break.

4.2. Current model of ore pass

The collected surveying observations, from payout counter, IMU and laser scanner, allowed for creation of string outlining ore pass walls and then for development of solids representing the current state of ore passes. The row string files contained significant level of "noise" and spurious points that had to be filtered before can be used for solids creation. The tools provided by mine design software were used to "clean" the raw survey data. Particularly, elimination of double-points and spikes was initially utilised to remove most of the spurious data. However, additional manual inspection, cleaning and editing, had to be applied. The solids were created using Vulcan3D software. To improve the stability of solid creation process and to reduce the size of individual triangulation files, the solids were created for ~100 m vertical sections of ore pass, Figure 14 (left). Creation of solids, representing sections of ore pass, allowed calculations of volumes and the assessment of wear and over break. Using the solids intersection capabilities of the Vulcan3D software (the Boolean operations on solids) the wear and over break volumes were extracted. As an example, the section volumes of Ore Pass #7 are presented in Table 2.



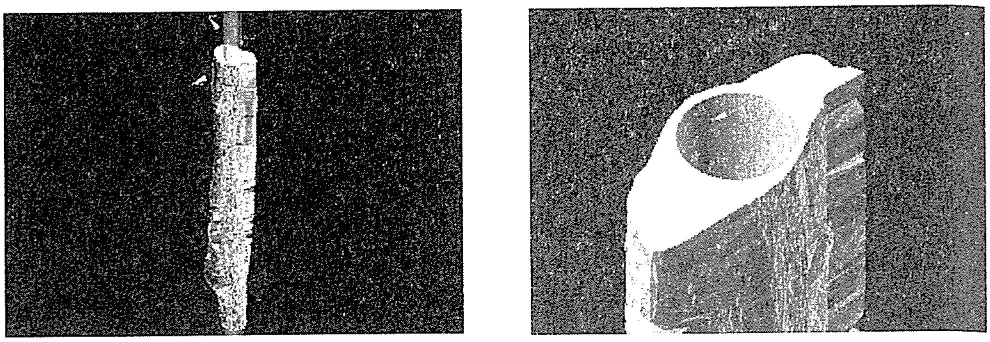


Fig. 14. Solid representing a section of ore pass (left) and ore pass wear and over break (right)

Rys. 14. Calizna przedstawiająca odcinek wyrobiska (lewa strona), zużycie wyrobiska oraz wyrobisko pionowe (prawa strona)

TABLE 2

Wear assessment for Ore Pass #7

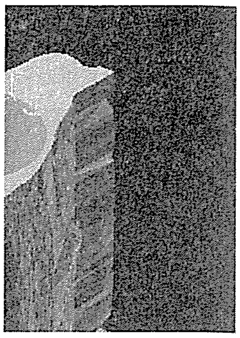
TABELA 2

Ocena zużycia Wyrobiska #7

Solid	Top Elevation	Depth	Initial Volume	Surveyed Volume	Wear & Overbrak	Unit Wear
36-top.00t	3684.909	84.81	1348.84	2080.63	731.78	8.63
35-36.00t	3600.099	184.70	1588.68	3925.97	2337.29	23.40
34-35.00t	3500.209	284.28	1583.82	4178.00	2594.18	26.05
33-34.00t	3400.625	385.12	1603.79	3305.87	1702.08	16.88
32-33.00t	3299.785	485.04	1589.03	2788.32	1199.29	12.00
31-32.00t	3199.873	526.89	665.58	1067.54	401.96	9.60

The obtained results suggest that the maximum ore pass wear develops in the middle of an ore pass depth. Review of the solids created for each section of an ore pass also suggests that the top section experiences the most irregular wear and failures of its walls. An example of ore pass wear in relation to its depth is presented in Figure 15.

The next step in presentation of the collected data could be an integration of the images, collected by side looking cameras, with solids that are build on strings created from lasers scans. Particularly, the collected images (video frames) can be used as texture patterns that are draped over the internal walls of solids. This should also allow for creation of 3D virtual model that may be interrogated by many mining specialists without putting them into dangerous environment and without interruption of ore pass operation. However, an efficient implementation of this data presentation technique requires significantly more research and development.



over break (right)

ɔbiska oraz wyrobisko

TABLE 2

TABELA 2

/ear & ɿerbrak	Unit Wear
'31.78	8.63
337.29	23.40
594.18	26.05
702.08	16.88
199.29	12.00
·01.96	9.60

ɔps in the middle of an
ɔass also suggests that
walls. An example of

gration of the images,
gs created from lasers
s texture patterns that
creation of 3D virtual
ut putting them into
However, an efficient
tly more research and

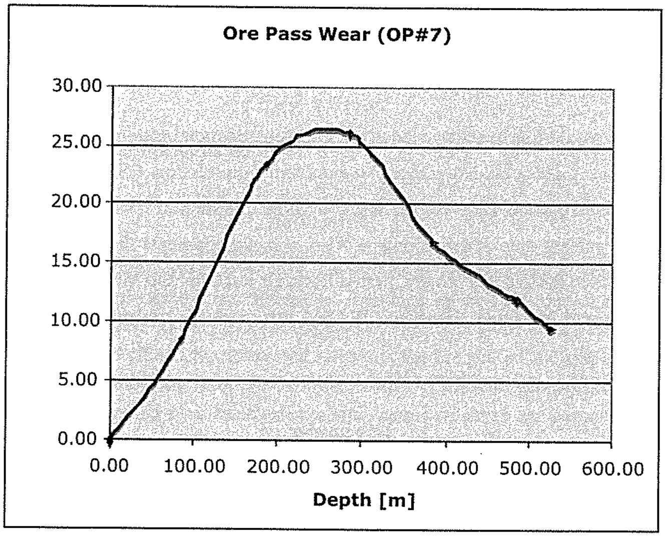


Fig. 15. Ore pass wear (OP#7)

Rys. 15. Zużycie wyrobiska (OP#7)

Conclusions and sugestions of further research and development

The developed ore-pass inspection and surveying system led to successful inspections and surveys of the Grasberg ore passes, one of the deepest in the world (~650m). As in any kind of research process, the research progress led to discovery of additional issues that had to be resolved. However, the time constrains did not allow for complete resolution of all such issues. At the second stage of the project, the scheduling pressures, to make VOIS ready for ore pass inspections in mid 2007, did not allow fully resolve such issues as: Implementation of full active gyro stabilisation of the pod; Further reduction of power consumption to achieve extended run times on a single battery charge; Optical alignment of cameras and improvement of illumination; Synchronisation of image capture with positional information collected by the pod. The new issues that arose as the visual inspection and laser survey was carried out were: Preparation techniques for ore pass to create suitable environment for surveying procedures and prevention of condensation of water vapour on internal laser optics.

Taking into account "what was learned" the following should be incorporated into the future VOIS designs: Heating system for laser scanner to stop condensation on its internal optics; Investigation of other methods allowing for collection of profile data not affected by mist or fog developing in ore passes; Further development of an active, gyro based, stabilisation control loop; Testing of alternate illumination systems, such as Light Emitting Diode (LED) or High Intensity Discharge (HID); Replacement of battery sub-system to reduce size and weight of the pod and the purpose built field control computer with single connection to the winch. The wireless communication system should also be considered, as well as, significant reduction of pod's weight and size.

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REFERENCES

[1] Fröhlich C., Mettenleiter M., 2004 – Terrestrial Laser Scanning – New Perspectives in 3D Surveying. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVI – 8/W2, 7–13.
[2] Logan A.S., Villaescusa E., Stampton V.R., Struthers M.A., Bloss M.L., 1993 – Geotechnical instrumentation and ground behaviour monitoring at Mount Isa Mine, Proceedings of the Australian Conference on Geotechnical Instrumentation and Monitorng in Open Pit and Underground Mines, 21–23 June 1993: Geotechnical Instrumentation and Monitoring in Open Pit and Underground Mining, ed. T. Szwedzicki. 321–329. Rotterdam/Brookfield: A. A. Balkema.
[3] Staiger R., 2003 – Terrestrial Laser Scanning Technology, Systems and Application, Proceedings of 2nd FIG Regional Conference, 2–5 December 2003. TS12 Positioning and Measurement Technologies and Practices. Marrakech, Morocco.
[4] Szwedzicki T., Cooper R., 2008 – Orepass Integrity in High Stress Conditions at Perseverance Mine, Proceedings of 10th Underground Operators Conference, Launceston, TAS, Australia, 14–16 April 2008.

ROZWÓJ SYSTEMU BADAŃ SŁUŻĄCYCH OCENIE WYROBISK RUDY (ORE PASSES) W KOPALNI GRASBERG MINE, PT FREEPORT, W INDONEZJI

Słowa kluczowe

Miernictwo, badanie, pionowe wyrobiska udostępniające

Streszczenie

System Pionowej Kontroli Wyrobisk (VOIS), opracowany w Western Australian School of Mines, umożliwia badanie oraz mierzenie wyrobisk udostępniających do głębokości 1000 metrów. Unikatowy system żyroskopowy stabilizuje gondole badawczą znacznie poprawiając jakość zgromadzonych danych. System został zmodyfikowany i rozwinięty, aby umożliwić badanie i mierzenie wyrobisk rudy w kopalni Grasberg Mine (PTFI), których głębokość sięga poniżej 600 metrów. Poprzez powiązanie danych zebranych przez system VOIS z danymi geologicznymi oraz geotechnicznymi, kopalnia jest w stanie lepiej planować i radzić sobie z utrzymaniem oraz naprawami tych wyrobisk.

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Exploration and Mining, PT
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ndon Stichbury from CSIRO

erspectives in 3D Surveying.
Information Sciences, Vol.

s M.L., 1993 – Geotechnical
lings of the Australian Con-
rground Mines, 21–23 June
round Mining, ed. T. Szwe-

lication, Proceedings of 2nd
surement Technologies and

itions at Perseverance Mine,
ustralia, 14–16 April 2008.

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School of Mines, umożliwia
katowy system żyroskopowy
ych. System został zmodyfi-
rasberg Mine (PTFI), których
zez system VOIS z danymi
ić sobie z utrzymaniem oraz

DEVELOPMENT OF INSPECTION SYSTEM FOR EVALUATION OF ORE-PASSES AT GRASBERG MINE, PT FREEPORT, INDONESIA

Key words

Surveying, inspection, vertical openings up

Abstract

The Vertical Opening Inspection System (VOIS), developed at the Western Australian School of Mines, provides inspection and surveying capabilities of vertical openings up to 1000 metres deep. The unique gyro system stabilises the inspection pod and significantly improves the quality of collected data. The system was modified and further developed to allow inspection and survey of the ore passes at Grasberg Mine (PTFI), which are more then 600 m deep. By combining information collected by VOIS with geological and geotechnical data, the mine is able to better manage and plan maintenance and repairs of these ore passes.