

+++ Best Practice +++ Application Note +++ Case Study +++

3D STOCKPILE, SLOPE AND SILO CONTOUR MEASUREMENT IN HIGH DUST AND FOG ENVIRONMENTS USING UNIQUE AND ROBUST 2D RADAR TECHNOLOGY

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Modern process control systems have contributed significantly to productivity increases within the raw materials industry. Determining silo volume and filling requires a multi-dimensional measurement. Slope profiles are scanned two-dimensionally using the machine's rotation and positioning information. Later, the 2D data can be condensed to a one dimensional process variable like m³ or % filling.

Mostly ultrasonic sensors are applied which are sensitive to strong winds and low pressure caused by high altitudes. Mines trying to reduce the error by using 2D laser scanners, discovered that these were sensitive to dust and fog.

Knowing these issues, the authors developed a new 2D radar technology which has been applied in Europe, Chile and Australia. Radar sensors offer significant advantages in tough environments like rain, dust, fog and snow.

The solutions are not only addressing the 3D volume calculation and visualization of stockpiles. Additionally, they allow measurement of the volume flow on conveyors. Furthermore the technology can be used for collision avoidance e.g. on bucket wheel excavators, stackers and reclaimers. This will not only increase the profitability and productivity. indurad also offers process automation and safety.

1. INTRODUCTION

This best practice shows innovative solutions using cutting-edge 2D radar sensor technology for mining and stockpiling operation. The Radar technology is a new way of solving a current industry need, currently lacking an online and real-time solution approach.

Based on fundamental laboratory experiments, comprehensive field-tests were performed in open-pit and underground mines. The indurad DualRangeRadar™ iDRR is available in a robust IP66 aluminium casing, optionally integrated

with the indurad Radar Processing Unit™ iRPU and a cramping box as shown in figure 1.



Figure 1: iDRR Radar in robust IP66 casing with embedded iRPU processor

In 2010 a coal shearer loader with the iDRR based radar collision avoidance solution has been awarded the bauma innovation award, after receiving the RAG research award in 2009. Besides the main working field in continuous mining operations which are dominating in Europe, indurad develops solutions for the large segment of discontinuous mining as well.

The 3D inventory control solutions like silo and stockpile measurements were demanded by the raw material handling industry. The key objective of the plant engineers is to have an exact measurement of volume and filling level of a silo or a stockpile with a volume accuracy of at least 95%.

Other typical requirements include:

- Online Updated Inventory Control
- Measurement while loading and unloading even with high dust exposure
- Maintenance free
- Contact-free passive scanning of the surface contour
- Integration into existing PLC control systems with additional expert access
- 3D visualisation of the stockpile for stockyard management
- Increasing productivity through faster, more transparent processes
- Prevention of overflow and drainage, improved health protection
- Optional: early warning system for bridging/agitation
- Telecommanding or even automated control of tripper car, stacker, reclaimer etc.

For inventory control reasons and stock market publishing obligations however, at least periodically, mines need a high accuracy and reliable volumetric information of the ore they handle in all stages of the process as well as the ore which they have in stock. Both was - for example - achieved manually, using laser measurements with all the problems addressed above. Besides the high personnel requirements, special measurement windows were required for the fragile and sensitive laser measurement devices to operate. For complete volumetric information, measurements from several different positions with limited or risky access are required.

2. TECHNOLOGY

Thanks to different wavelengths of laser light (approx. $1\mu\text{m}$) and radar (4mm), the impact of environmental conditions on the quality of the radar measurements are minimal. While the radar “overlooks” small particles, laser light reflects on dust and fog, leading to a dispersion of the laserlight. Laser, other than radar, cannot detect objects lying behind the dust or fog curtain.

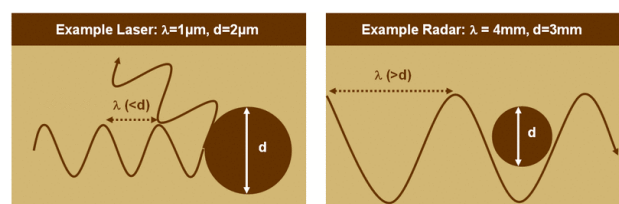


Figure 2: Influence of Dust on Laser and Radar

Laser scanners deliver accurate measurements. Despite an availability of >99%, these sensors do not supply usable data in tough environments which are quite common in the mining industry such as fog, dust, rain or sensor pollution. But assistance and safety is first and foremost needed under these conditions. The application of radar sensors in tough environments leads to a higher

plant availability and can be a useful safety back-up to laser based solutions. Figure 3 highlights the key differences between radar systems and established laser scanners from Sick or Riegler.

RELEVANT CRITERIA	LASER	RADAR
Distance Measurement	✓ Very High Accuracy < 10mm	✓ High Accuracy < 50 mm
Angle Measurement	✓ Very High Accuracy < 0,01°	✓ High Accuracy < 0,1°
Speed Measurement	○ Multiple Measurements Algorithm	✓ Single Measurement Physically
Sharpness	✓ Very High Accuracy Point Beam	○ Medium Accuracy Lobe Beam
Interpolation	○ Indirect – Point Reflection Averaging of Multiple Data	✓ Direct – Area Reflection Automatic Averaging
Object Size Estimation	○ Indirect Complex Algorithms	✓ Direct Amplitude RCS/dBsm
Small Structures	○ Reduced Meas. Frequency Only through dense Sampling	✓ Constant Meas. Frequency Detection of thin Ropes
Occlusion	○ Only Foreground visible Point-beam interrupted	✓ Fore- and Background Lobe passing small objects
Vibration, Shock, Maintenance	○ Medium Sensitivity Optical Components	✓ Low Sensitivity No optical Components
Dust, Fog	✗ High Sensitivity Especially Near Range	✓ Low Sensitivity Complete Range
Dirt on Sensor Window	✗ Transparency Required Scheduled Cleaning	✓ Thin Coating Problem Free Low Cleaning Requirements
SUITABILITY FOR REAL TIME AUTOMATION IN MINING	○	✓

Figure 3: Benchmark of Laser vs. Radar by a large set of potential criteria

The Indurad Dual Range Radar™ iDRR is a highly sophisticated and compact radar sensor for industrial applications. Contrary to industrial level radar systems of established manufacturers, the iDRR measures not only linear distances, but a two-dimensional surface profile, within 0.066 seconds at a range of >100m and an accuracy of < 0.05m. The detection range is divided in a high and medium accuracy sector, like shown in figure 4. Usually the high accuracy sector is used for surface profiling, the medium accuracy for collision avoidance. Furthermore the sensor beam can be adjusted ±16° via software°. This function reduces the cost for accurate mechanical mounting and adjusting, even allowing a 3D scan in silo applications. The beam-slice itself is with ±2° highly focused enabling a very selective detection of objects and minimizing of ghost targets and resulting false detections.

If the radar is installed on vehicles like haul trucks, the beam direction can be adjusted individually, for example depending on the load (full/empty).

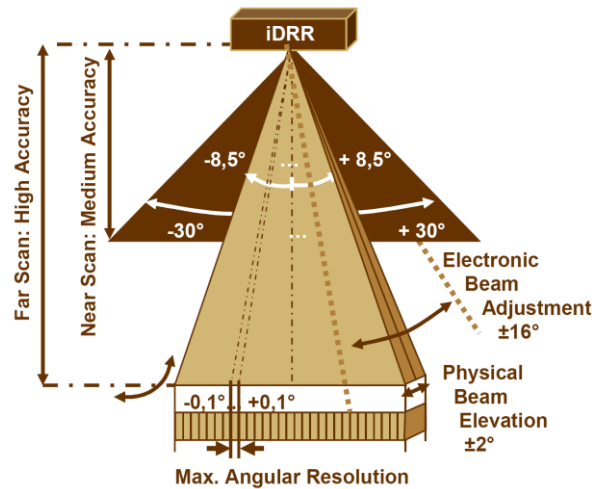


Figure 4: Detection Range of the Indurad Dual Range Radar iDRR

Besides the advantage of a second/third measurement dimension, the 2D iDRR differs from the common 1D level gauge radar sensors in other important criteria as well. Especially under narrow or highly dynamic conditions, common level gauge radar sensors have difficulties, caused by a low update rate which is a result of the ultra-low power design for ATEX intrinsically safe applications. The iDRR however is completely optimized for performance – the 8 Watt sensor is even available in an ATEX flameproof enclosure reaching the same certification level another way. The following figure 5 helps to understand the differences depending on the individual needs.

RELEVANT CRITERIA	Indurad iDRR Radar	Level Gauge Radar	Relevance	Important for...
Measurement Frequency	15 Hz 0,066 sec	0.2 – 1 Hz 1 - 5sec	High	Dynamic Environments
Highly Customizable Noise Filter	Yes	No	High	Narrow Installations
Latency, Integration Time	Low	High	High	Real Time
Short Wavelength	Yes, 4mm	No, 12mm	Medium	Fine Material
Data Dimensions	2D (multiple range, angle)	1D (single range)	Medium	Uneven Surfaces
SUITABILITY FOR TOUGH ENVIRONMENTS	✓	○		

Figure 5: Benchmark of 2D iDRR Radar vs. 1D Level Gauge Radar

3. CHALLENGE AND REQUIREMENTS

Established 1D radar sensors like the Vegapuls 68 or the Endress+Hauser FMR250 provide exact measurements of a small surface area of the bulk material (1D Measurement). Despite a high accuracy in distance measurements, the subsequent determination of the volume or mass from this data, though, is still prone to error due to missing information concerning the surface contour. This is shown in figure 6 using a real world model example. It illustrates how the calculation produces different volumes when the silo has recently been loaded (cone shape) and when it has been unloaded (funnel shape). In this case the determination of the filling volume yields an error of >30% (a few hundred tons) due to the simplified model of a plane material surface that cannot be compensated by any mathematical model.

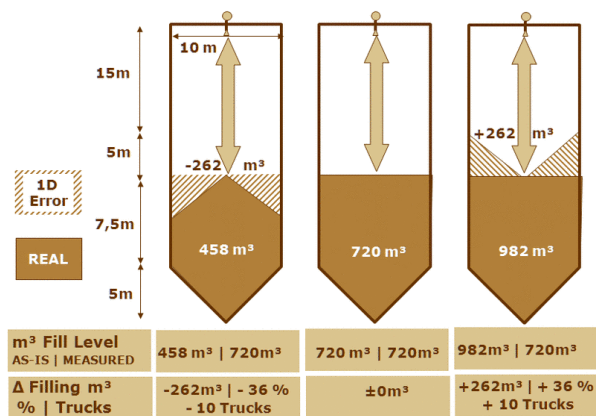


Figure 6: Influence of the surface profile on the Volume calculation

A model based mathematical compensation of the error is not possible due to the fact that the exact contour of the lime surface is unknown and cannot be derived from the measured data. The closer the 1D radar is positioned to the silo walls, the more inaccuracies in the measurement can be

expected (reflections from welding seams, adhesive material, etc.)

In the cement industry, stocks are kept low due to the high working capital. This is also the fact prior to planned servicing of the rotary kiln. When inaccurate 1D measurements are applied it often happens that bunkers are physically empty although the ERP system still shows leftover stocks. In this case, cement producers have to obtain stocks from competitors in order to fulfill their contracts. The exact 2D/3D stock information provided from the iDRR can ensure that the balanced raw material actually is in stock when a part of the facility is planned to be serviced.

The requirements of a volume and fill-level measurement system can be summarized as follows:

- Scanning of surface contour
- High accuracy >98%
- Constant updating of 1x per second
- Measurements while loading and unloading with high dust exposure
- Integration into existing control system with additional expert access
- Maintenance free

4. APPLICATIONS AND CASE STUDIES

indurad has been addressing the need of the industry with developing both sensors and complete integrated solutions. In this chapter, three common applications like Silo, Tripper Car and Stack-er/ Reclaimer are presented.

Solution for Bucket Wheel Excavator

The large dimensions and resulting blind spots of large bucket wheel excavators make it difficult for operators to observe the environment to avoid collisions and estimate ranges for excavation control. Figure 7 shows the dimensions of such a machine (top left) including the position of the iDRR radar array, a 3D illustration of the position of the iDRR array on both sides (bottom left), a picture of the bucket wheel in front of the slope (top right) and the slope collision scenario (bottom right) with gear box, bucket wheel bearing and operator cabin, the flexibly adaptable collision zones (top centre) in green, yellow and red.

indurad has been commissioning the 2D radar which, on one hand, addresses monitoring the collision zone besides a large bucket wheel while, on the other hand, providing accurate surface data for a predictive volume control. To deliver a maximum accuracy, on both sides of the bucket

wheel, an array of five radar sensors is applied. To demonstrate the reliability of the solution, the client covered the iDRR sensors in a mixture of mud, clay and coal, as shown in Figure 8. The signal intensity of the radar has been attenuated by the coverage, but still remained accurate and reliable for performing the objectives.



Figure 8: Radar blockage test with mixture of clay, sand and coal

The radar data is captured from both radar arrays and transferred to the indurad Radar Processing Unit iRPU. Furthermore, GPS positioning information from multiple antennas on the boom is fed

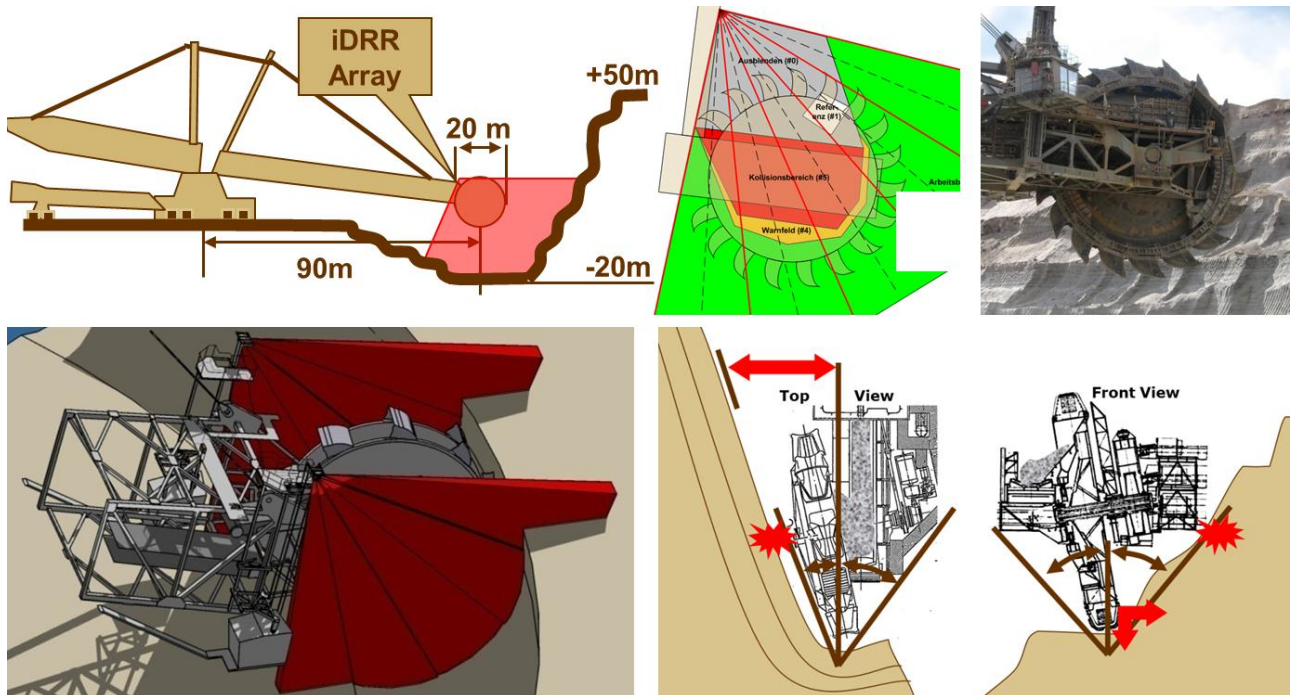


Figure 7: Radar Array installation on a bucket wheel excavator providing data for collision avoidance and predictive volume control

to the iRPU, providing the position of both arrays as well as the orientation in roll, pitch and yaw. On the iRPU, the radar raw data is processed and then split to two algorithms – surface profiling and collision avoidance. For surface profiling, the raw data is filtered, smoothed with sophisticated statistical functions and then merged with GPS data to 3D Gauss-Krüger-Coordinates. The iRPU then delivers continuous, accurate and real time data of the surface in 3D for the mine model and for the predictive volume control (i.e. cutting depth and swing speed).

In the course of a performance test, the iDRR Array has been audited to an expensive and surveyor grade Riegl Q120i Laser Scanner. The laser data has been processed on a different PC using the same GPS data; however, both were not ideally time synchronized resulting in slightly different

sensor data and GPS matching. Furthermore, both laser and radar have been installed a couple of meters apart from each other, while the 3D offset has been compensated for, as exact as measuring accuracy allowed. The comparison has been performed during full operation at a swing movement with all common vibrations. The results were highly impressive, even without these negative circumstances: Calculating the distance of both planes at randomly chosen 40 000 points in 3D, a standard deviation of 0.159m and a gauss peak offset of 0.031 m could be determined. In the following figure 9, the distance of the planes is colour coded and supplemented by the histogram. In the figure, a red colour indicates that the laser was above the radar plane, blue indicates that the radar was above the laser plane. In the top-right corner, a common slope profile is illustrated.

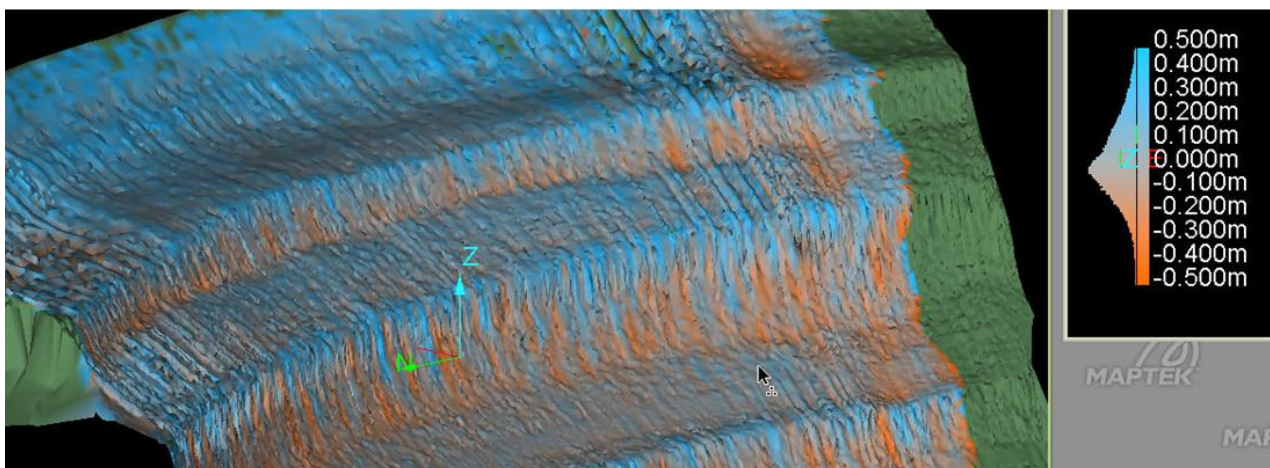
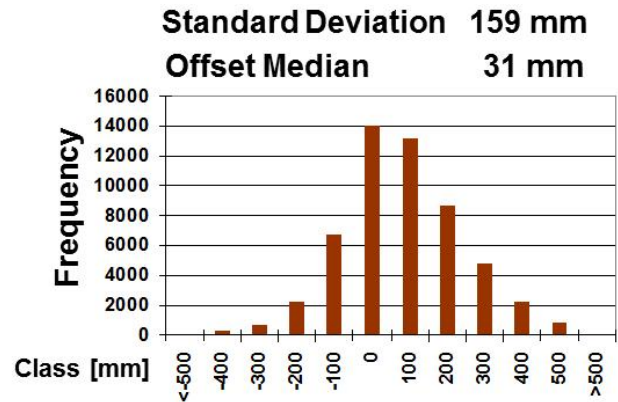
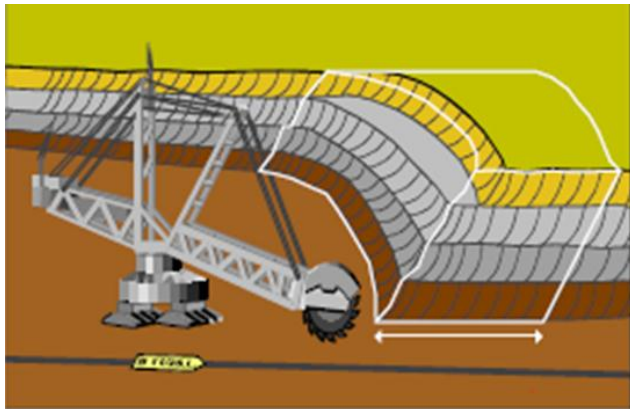


Figure 9: ± 0,5m Color Coded Distance of the Radar Surface Measurement and the Laser Surface Measurement at good conditions (needed for the usage of the laser)

Solution for Iron Ore Stockpile with Stacker

The Australian iron ore stockpile is fed by a Tripper with approximate 1500 t dumping capability per hour, building a stack with a length of 500 m of magnetite & hematite iron ore in a windrow or a cone format (cf. Figure 10). The operator had a tough job keeping the dumping height as low as possible to minimize dust, preventing of over and under filling as well as avoiding collisions. As the problems in daily operations were substantial, the plant asked indurad to develop an operator assistance solution while providing process transparency for the management and engineers.



Figure 10: Tripper with Stacker (top right), Transfer Point Tripper to Stacker for Volume Flow Measurement (top left), Boom with Windrow Cones in background (bottom left), Stacker boom head idler pulley (bottom right)

The customer specified the following requirements before the project started:

1: Collision Detection: One of the problems is stacker collision with the stockpile, if the operator misjudges stacking requirements or in case of component failure. Presently collision protection is provided by lanyards on each side of the boom and a tripper switch at the boom head. This is aggravated by operational personnel being unable

to see the stacker due to dust & other stacks etc. in their line of sight. This was supposed to be replaced by an electronic radar fence.

2. Dust Mitigation: Another problem is dust creation due to inappropriate height control while stacking, being made difficult due to the geometry of the stack and stacking angle of the boom. For this, a radar based dump height control needs to be established.

3. Long Travel Control – Belt Volume Scan: Presently the windrow height is controlled by the long travel speed via a belt weigher, with no method of adjustment for material density. Thus, the volume of the iron ore travelling on the belt was supposed to be measured to replace weight for this purpose.

4. Long Travel Control – Positioning: The stacker long travel position is presently supplied via encoders on the stacker wheels; this is to be replaced by a robust distance measurement system which can penetrate dust.

5. Process Visualization: All information gathered should be collected in a database for further analysis. The surface profiles scanned by the radar sensors should be used to create a 3D Volume model using the existing luff and slew absolute encoders. The visualization should be available for engineers as well as quality and sales people in the management.

All objectives could be reached using four iDRR sensors plus two iATR distance measurement devices. Within the specification phase it was decided, that one iDRR will be installed on both sides of the idler pulley at the stacker head, one iDRR below the boom for collision avoidance and one iDRR over the belt on the tripper car for volume flow measurement. All devices can be seen in the following Figure 11.

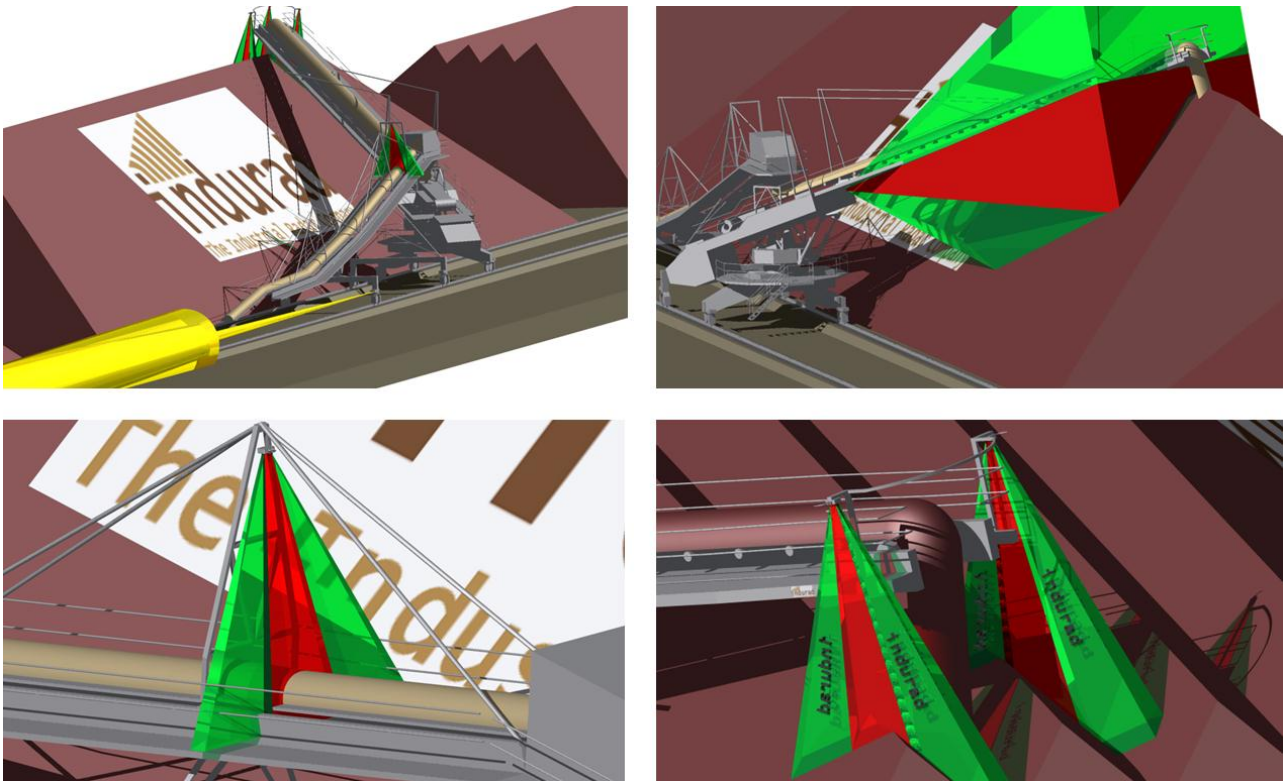


Figure 11: Tripper/Stacker Positioning with yellow iATR (top left), Collision Detection for Boom (top right), Belt Volume Scan (bottom left) and Dump Height control (bottom right)

Using the iDRR close to the boom’s pivot point as well as the two sensors at its head, the 3D coordinates of the heap surface are being determined from the positions of the installed components using the luff angle encoder, the slew angle encoder, and the tripper’s position that was determined by the indurad ActiveTransponderRadar iATR. This data is then being processed and shadowed areas are inter- or extrapolated using boundary conditions (like the repose angle). Another process is the determination of the heap’s volume (figure 12). The heap can be captured with a profile accuracy of <math><0,1\text{ m}</math>. The inaccuracies of the rotary encoder as well as the distance measurement simply lead to a model shift and do not result in a volume error.

The heap volume is visualised on a Thin-Client Webserver (iWEB) thereby enabling all authorized

personnel to access the data via Ethernet. Through the compact and integrated implementation, high integration costs from SCADA solutions can be avoided. This also provides access to the log files. Figure 13 below illustrates the iWEB Thin-Client solution for an integrated belt volume scanner.

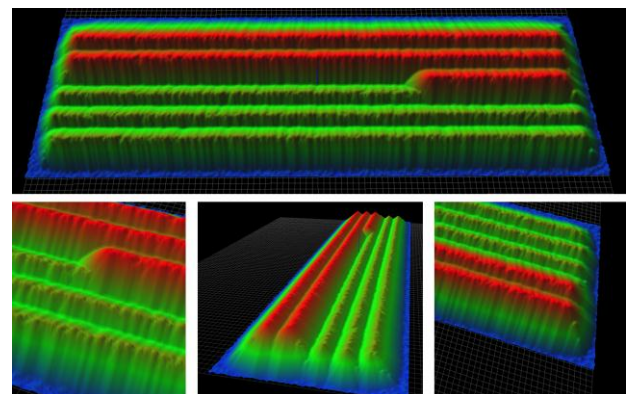


Figure 12: 3D Stockpile Model calculated from radar data used for volume calculation

The stacker long travel control is based on the indurad Belt Volume Flow Solution, measuring the material cross section and multiplying it with a velocity parameter. The measured data is stored for analysis on the iWEB thin client webserver for further analysis (Figure 13). As the velocity of the conveyor is fix in this case, the customer does not need the indurad Doppler Velocity Radar iDVR for speed control. Finally two indurad Active Transponder Radar iATR Sensors have been installed, one on the tripper/stacker and one at the end of the rail track enabling an accurate positioning measurement with $\pm 0,05$ m accuracy.

In the industry, the volume flow measurement on conveyors is realised mainly via load cells using fixed density parameters. In some applications laser scanners are used, as they do not require a complex mechanical integration and frequent calibration. However, laser based systems are prone to downtime caused by fog and dust; furthermore

they can send false information which is more critical than no information. Figure 14 depicts the sensor set up for mass flow measurement. The large picture shows, how dust affects a Sick LMS outdoor laser scanner (red), while the iDRR radar (blue) is not affected. The other two pictures highlight that radar detects the mass flow within the same boundaries, offering a comparable accuracy at higher robustness.

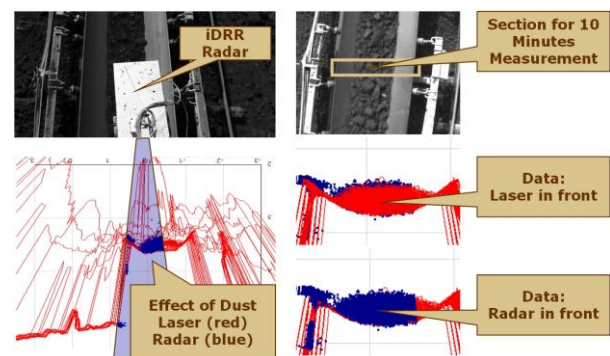


Figure 14: Results of 2D Radar and Laser for Mass Flow Measurement

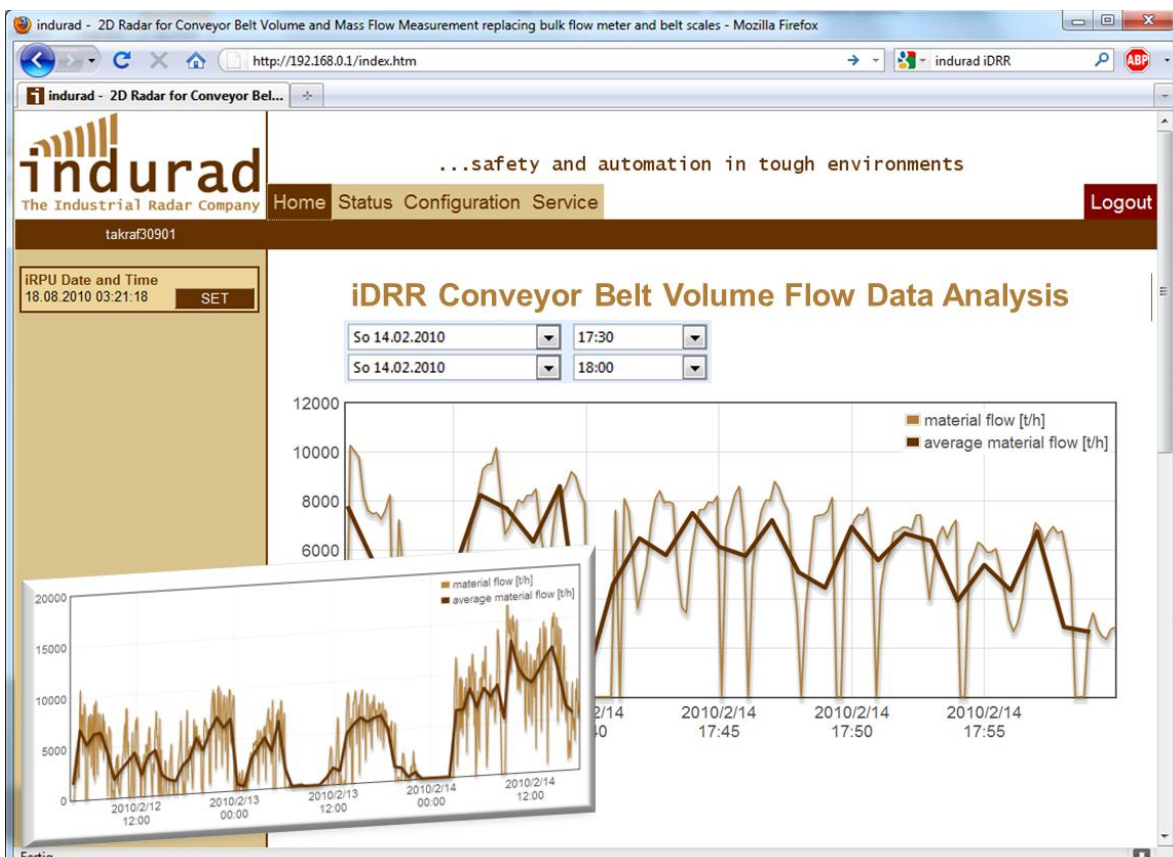


Figure 13: iWEB Thin Client Web Server for Data Analysis on iRPU

Solution for a crushed Copper Ore Stockpile with Tripper Cars

The stockpile for copper-ore at a large mine in Chile's Atacama Desert is being loaded using a "Tripper-Car", as shown in figure 15. So far the stockpile is manually measured once a week using a mobile laser measurement device. Since gaining access to the heap is difficult, the instrument engineer has to spend a significant amount of time in the hazardous area. Furthermore sporadic funnel shaped slumps can remain undetected. To provide a more accurate model for stockpile building, process cycles and balancing of masses, a reliable measurement was required that can provide the current volume and volume distribution in short intervals or in an on-line model.



Figure 15: Closed Copper Ore Stockpile with Tripper Car Feeding

The solution is based on four iDRR sensors that can map the stockpile in a 2D cross-section profile (see figure 16). Through movements of the tripper car the sensors can also map the third dimension. The 3D modelling of the stockpile requires an exact identification of the tripper car's position along its track. This is realised through robust

indurad Active Transponder Radars (iATR) for distance measurement with a 0,1 m accuracy that are based on the same physical measurement processes as the iDRR sensor.

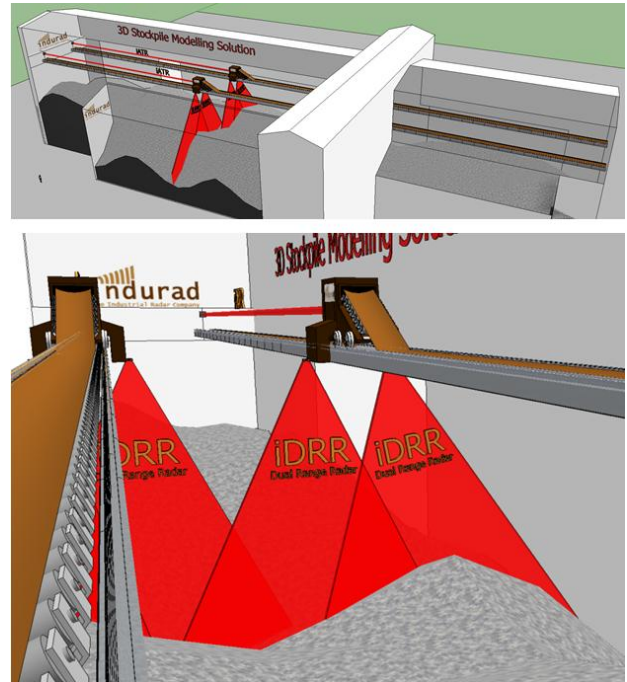


Figure 16: Two iDRR Sensors on both Tripper cars scanning the stockpile whereas the tripper car position is measured with one iATR device on each tripper car and one central device

All data is being funneled through the iRPU. The indurad software merges the data from the iDRR with the iATR's positioning data and generates a 3D model of the stockpile with mass and volume information, as shown in the previous applications.

The next step can either be the telecommanding or the automated control of the storage area. All necessary sensor information is already available in the current configuration level (position of tripper car, surface contour of the stockpile), so the upgrade can simply be done with new software.

Solution for Coking Coal Silo

In this example, several fairly symmetrical coking coal silos with an inner diameter of 14 m and a height of 25 m respectively 50 m were regarded. The coal is inserted into the silo via four intakes in the roof, thus producing an asymmetrical surface contour (see left picture in figure 17). The iDRR radar was installed in the center of the silo. Due to the rugged radar measuring technology, the coal and coal dust surrounding the sensor do not affect the measurement accuracy. Utilizing the Doppler-Effect, falling pieces can be distinguished from the bulk material surface.

The sensor captures a two dimensional surface profile in an angle of $\pm 25^\circ$, 15 times per second (figure 17, bottom right). In this process, the radar does not only capture a line in its $\pm 2^\circ$ measuring cone but a strip. If this strip is tilted compared to the measuring range, the radar captures reflections of various adjacent points projected to the 2D measurement plane. Since dynamic effects can be disregarded, the 2D radar cone can be periodically pivoted to produce a 3D map of the surface (figure 17 on the left).

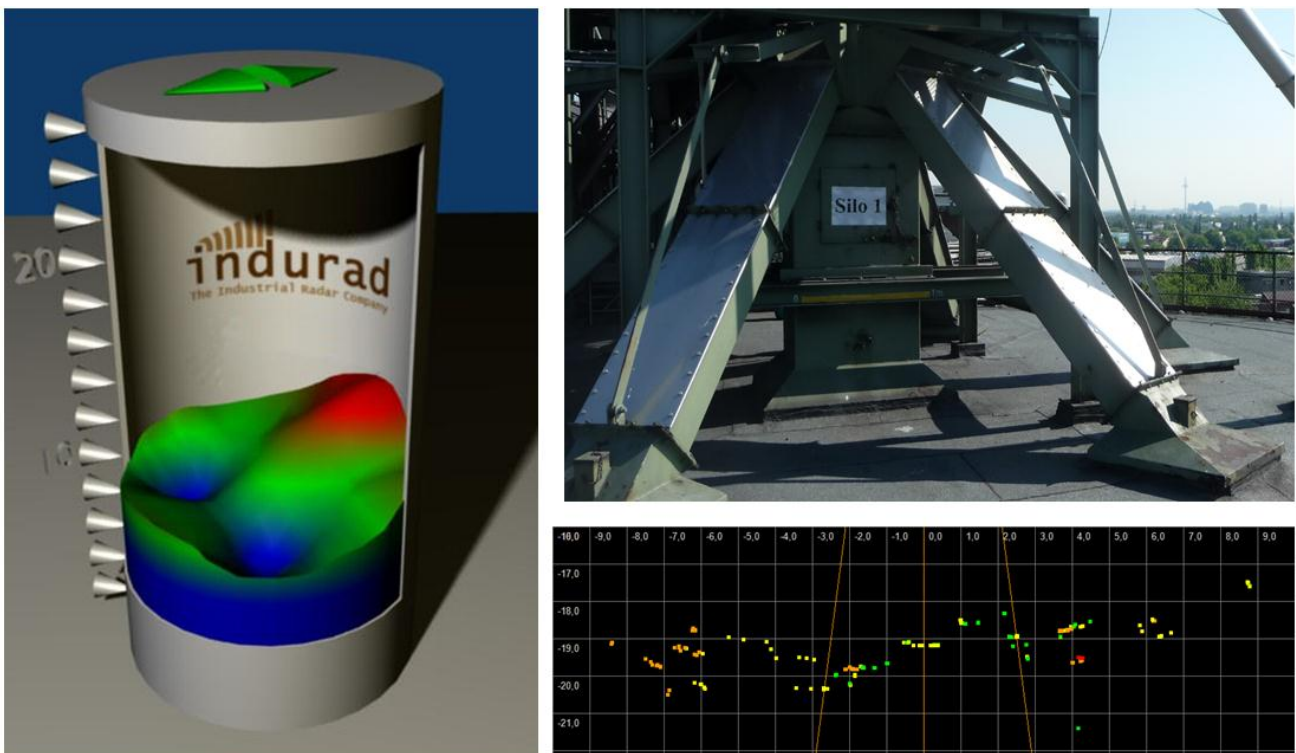


Figure 17: 3D Visualization of bulk material surface (left), Silo with filling tubes (top right) radar raw data of cross section with 1m grid (bottom right)

SYSTEM CONFIGURATION

The raw data of up to twelve iDRR sensors is sent via extremely robust CAN Bus to the indurad Radar Processing Unit™ (iRPU) where it is processed depending on the individual application. The processing includes signal processing, sensor fusion, volume calculation and 3D modelling based on the individual installation positions and stockpile/silo geometry. For the 3D modelling of large stockpiles with a moving iDRR, further external sensor information like inclination sensors, slew sensors or GPS information or the indurad Active Transponder Radar™ iATR for absolute positioning need to be integrated. Depending on the customer's preferences, the data can be sent on different interfaces depending on the information depth, as shown in Figure 18.

The configuration of the indurad solutions can be done via a web interface, as shown in figure 19. Besides data analysis and configuration it allows

remote firmware updates and upgrades in case of a future change in the process.

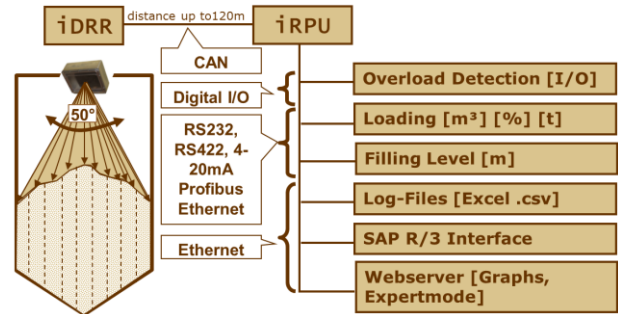


Figure 18: Integration of the Radar in the Process Control System

Logfiles (for example .csv for analysis with Excel) containing volume changes or even radar raw data for indurad expert analysis can be downloaded as well via mouse click. Additionally, the data can easily be accessed from a standard computer via the indurad iWEB Webserver through the mine network, including all information like 3D Visualisation, filling level and data for historic one click analysis.



Figure 19: Thin Client Webserver for system configuration, data analysis and diagnostics

CONCLUSIONS

The radar hardware and software solutions developed by indurad enable significant process optimization in rough environments, in which traditional sensor technology from the manufacturing industry reaches their limits. With the indurad solutions, potential can be unlocked in every mining, processing and stockpile operation across the resources industry. The 2D iDRR technology has a high impact on safety, process control and inventory control.

In the field, the iDRR technology has proven to be highly applicable. The measuring process allows for a profile accuracy of up to 0,03m, depending on the effort put into calibration of the equipment. The measuring frequency of 15Hz proved to be of great advantage, too. The equipment is insensitive to environmental stress like dust, rain, fog or snow and the sensor technology even provides adequate measurements when in motion, with high dynamics in the silo or while loading and unloading of trains.

The unique solutions will create substantial benefits and advantages, thereby yielding maximum customer value:

Technically:

- 2D profile scanning for high accuracy
- Insensitive to high environmental stress (dust, vibrations, wind, etc.)
- Constant update of the model at a measurement frequency of 15Hz
- Complex volume measurement and mass calculation by bulk density

Engineers & Process:

- Management process transparency by inventory and mass flow

- 3D visualization for material distribution and improved dispatching

Management & Sales

- Permanent online status of heap / stockpile information and history
- Planning tool for improved production and sales

Maintenance & Instrumentation:

- Zero Maintenance as merely one initial parameterization is required
- Collision Avoidance by Detection of Stockpile and Machinery

The global trend in the mining industry towards increased demand for assistance and automation solutions facilitates the developed technology in a way that it is anticipated to be an integral part in most future mining equipment concepts.

The development of the basics of the 2D radar technology has been supported by customers like OEMs and mining operations as well as the research expertise of the IMR of the RWTH Aachen.

About indurad GmbH

The indurad GmbH develops, produces and installs customized 2D radar solutions. indurad sees itself as a supplier of ready-to-use systems that understands the processes and customer requirements of the extractive industry. The 2D radar sensors developed by indurad are successfully applied all over the world, even in areas of high environmental stress.

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