Toward the Fully Digital Mine: Autonomous 3D Monitoring with *RIEGL* Terrestrial LiDAR

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Abstract

Mining operations increasingly depend on monitoring systems that can deliver reliable spatial information to support safety-critical and operational decisions. This paper discusses the role of autonomous terrestrial LiDAR in that context and explains how *RIEGL* laser scanning technology can contribute to the development of a fully digital mine. Instead of treating geotechnical monitoring as an isolated survey activity, the document presents it as a connected risk-management workflow in which dense 3D surface data, automated processing, web-based visualization, and alarm communication are combined into a repeatable operational process.

The paper focuses on the practical value of *RIEGL* terrestrial laser scanners in mining environments, where long range, harsh environment, restricted access, and rapidly changing terrain create demanding measurement conditions. It compares LiDAR with established monitoring technologies such as total stations and radar and shows how these systems can complement each other. Particular attention is given to the flexibility of the *RIEGL* sensor platform, which can be utilized for static surveying, mobile mapping, and permanent autonomous monitoring. The *RIEGL* Monitor+ App is presented as the central software environment for onboard acquisition, alignment, epoch comparison, cluster-based change interpretation, prism monitoring, design comparison, slope-angle analysis, web publication, and threshold-based notifications.

The document combines a technical overview with short interview passages that provide practical field perspective. These interview sections are intended to complement the main text and are presented in italic type in the document. They reflect the experience of Adrian Wall, Superintendent Survey at Yancoal Australia Ltd. He operated the LiDAR monitoring system during a six-month proof of concept in an active mining environment. The interview content illustrates how the system performed under real site conditions, including weather exposure, field-safety requirements, integration into existing workflows, and communication of monitoring results to operational stakeholders.

The main body of the paper addresses the monitoring concept, workflow, and value for mine risk management. More detailed technical explanations are provided in the appendix section after the main text, covering selected technologies, system components, data formats, configuration methods, web-viewer functions, and data synchronization. QR codes in the appendix link to additional *RIEGL* datasheets, info-sheets, manuals, training material, and technical papers for readers who wish to explore individual topics in greater depth.

1 From Monitoring Requirement to Digital Mine

Mining companies are working in an environment where safety, productivity, environmental responsibility, and planning reliability are increasingly linked to the quality of their spatial data. As open pits become deeper and broader, waste dumps and tailings facilities grow in scale, and production areas change more rapidly, geotechnical monitoring is no longer a supporting activity at the edge of operations. It has become a central part of how mines protect people, safeguard assets, and maintain continuity of production.

In this wider risk-management context, monitoring data must do more than document the mine after the fact. It must support continuously updated situational awareness, reduce the blind spots between isolated survey campaigns, and help technical teams understand whether observed changes are local, temporary, or part of a developing geotechnical trend.

This development is closely connected to the wider idea of the fully digital mine. In practical terms, that concept describes an operating environment in which decisions are based on connected sensors, automated workflows, and data that can be evaluated without delay. In such an environment, monitoring is no longer understood as a periodic survey carried out every few days or weeks. It becomes a continuous, near-real-time source of information for planners, geotechnical teams, and operational managers. That shift raises expectations. Mines need monitoring data that is precise, reliable, spatially dense, and available fast enough to support action.

Traditional methods still play an important role. Prism monitoring with robotic total stations remains highly valuable where individual control points must be tracked with millimeter precision. Ground-based radar is an established tool for detecting very small movements over large areas and at long distances. Yet both technologies also have structural limitations. Total stations measure only where prisms have been installed. Radar detects movement only along the line of sight, but it does not provide a full three-dimensional surface model. Many mining-related deformation processes, however, are spatially complex. They develop across surfaces, through zones, and over time in ways that cannot always be captured sufficiently by single point data (total station) or spatial low resolution 2D line-of-sight information (radar) alone.

The most robust monitoring strategies therefore combine complementary technologies rather than treating them as competitors. Total stations provide precise control at selected points, radar contributes high sensitivity to line-of-sight movement, and LiDAR adds dense three-dimensional geometry (Fig. 1). The added value of LiDAR is especially strong where the spatial extent, volume, and shape of a deformation zone are as important as the displacement magnitude itself.

The trend toward denser monitoring is driven by the actual behavior of mining slopes and structures. Geotechnical processes are rarely linear. Small displacements in a berm, subtle settlement in a dump, or localized movement on a pit wall may appear minor in isolation, yet they can indicate broader instability developing over time. What operators need is not only the ability to detect that movement exists, but the ability to understand its geometry, extent, and progression. Dense 3D monitoring with *RIEGL* terrestrial Laser Scanners (TLS) adds that context. Instead of asking whether a single target moved, engineers can ask which part of a slope changed, how far the affected zone extends, whether material was lost or accumulated, and whether the pattern aligns with expected geological or operational controls. That kind of interpretation is central to responsible risk management in large-scale mining.

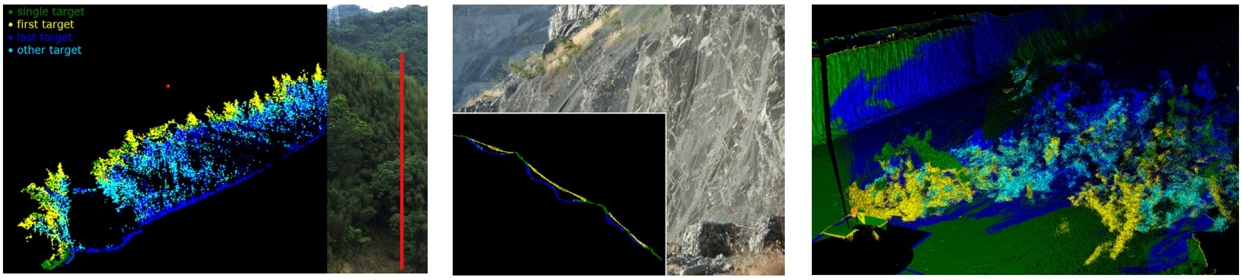
Criteria	**Total Station**	**Radar System**	**LiDAR (*RIEGL* TLS)**
Data Coverage	Point-based (prisms)	Surface (2D)	Full 3D surface (point cloud)
Accuracy	mm	mm	mm-cm (surface, range dependent), mm (prism)
3D Capability	✗	✗	✓
Flexibility	Low	Moderate	High
Weather Robustness	Moderate	High	High (except extreme fog/rain)
Maintenance Effort	High	Medium	Low
Cost	Medium	High	Medium

Figure 1: Comparison table of the established hardware solutions

This is where terrestrial laser scanning has established a strong position. LiDAR-based monitoring creates dense three-dimensional surface information instead of isolated observations. It allows mines to document current terrain conditions, compare consecutive monitoring epochs, and analyze how changes evolve across the full observed face, bench, dump, or dam. The practical value is not simply that more points are measured. The real value lies in the ability to describe deformation spatially and temporally in a consistent way. That makes it easier to distinguish local anomalies from broader movement patterns, to quantify affected areas and volumes, and to relate observed changes to geology, mine design, and operational activity.

For mining users, the sensor platform itself matters just as much as the method. *RIEGL* terrestrial laser scanners have been developed in a way that addresses the realities of mine sites: long ranges, harsh environmental conditions, and the need to switch between different operational tasks without changing the underlying data logic. Since the introduction of *RIEGL's* V-Line technology, full waveform processing has enabled detailed signal analysis including multi-target capability and measurement attributes like deviation and calibrated amplitude/reflectance (Appendix 1). In practical mining terms, this matters wherever surfaces are partially obscured by dust, vegetation, safety wires, or other intervening objects (Fig. 2).

> ***Interview:***
> *Q: During the trial, how did the system perform when visibility and weather were not ideal?*
>
> *A: The system ran continuously throughout all weather conditions including heavy rain, wind and dust. Although not every scan looked perfect, the bulk of the useful data for interpretation was still there. At long range we could see the relevant slope geometry and distinguish surface change from temporary noise as expected. Combining the monitoring with multiple targets helped where the line of site was affected by vegetation and dust. For site, the practical value was continuity: we did not have to stop the monitoring record every time conditions became less than ideal. We still reviewed the data to ensure it was free of gross error, but the system gave us a more complete picture than a simple pass-or-fail measurement would have done.*



vegetation safety wires dust

Figure 2: Multi-Target Detection (dark-blue is showing the last target detection)

Over time, this platform has also been extended toward longer-range applications. The *RIEGL* TLS portfolio offers scanners with up to 6500 meters measurement range, which is particularly relevant for very large open pits and for remote observation of highwalls or slope sectors that cannot be approached easily. Multiple-Time-Around processing (Appendix 2) helps maintain reliable long-range measurements even at high pulse repetition rates. In combination with external sensors for temperature, humidity, and pressure, the system can also account for atmospheric effects that become increasingly relevant over longer distances. These characteristics reinforce the value of LiDAR in mining not only as a dense 3D measurement method, but as a platform designed for mapping realistic site conditions where visibility, access, and range requirements can vary significantly.

The VZ-i series added another decisive element: onboard processing based on an embedded Linux environment that allows custom applications to run directly on the scanner. This embedded intelligence changes the role of the scanner. Instead of being just a sensor that produces raw data for later office processing, it becomes an autonomous measuring and analysis node. Data can be acquired, transformed, evaluated, and published at the edge, directly when the measurement is taking place. In mining, where unstable zones may be remote, dangerous, or difficult to access, that is more than a convenience. It reduces latency between acquisition and interpretation, lowers dependence on external post-processing workflows, and supports a monitoring philosophy that is better aligned with modern risk management.

A comparison with established technologies illustrates why this is important. Total stations remain the reference where mm-level precision at individual prisms is required, but they demand installation, cleaning, remeasurement, and maintenance of physical targets in potentially hazardous areas. Radar can identify very small movements over large surfaces, but its spatial representation is coarser and its observation geometry remains 2D limited to the sensor's line of sight. LiDAR occupies a different position. Surface measurements in full 3D with high accuracy even at ranges up to 6500 m. *RIEGL* scanners can even perform prism monitoring with millimeter accuracy. Above all, LiDAR provides a full 3D description of the monitored scene, supports volumetric analysis, and captures changes along the local surface normal rather than only line of sight toward the sensor. In a modern mine, that combination of dense geometry, flexible deployment, and direct integration into digital workflows makes it a particularly comprehensive complement within a multisensor monitoring strategy.

> ***Interview:***
> *Q: How did the LiDAR-based approach change the amount of field work needed around prisms and monitored areas?*
>
> *A: The Lidar based approach meant that we didn't have to place people in hazardous areas to install monitoring targets. This saved my team a large amount of time in the initial setup and ongoing maintenance of the monitoring project. The Lidar based approach gave us dense surface information without the need for a comprehensive prism grid. From a site perspective, this is a real safety enhancement for the field team, eliminating them working in hazardous areas, not just a measurement benefit.*

2 *RIEGL* LiDAR Platform: Three Operating Modes with One Sensor

One of the strongest practical arguments for terrestrial laser scanning in mining is operational flexibility. A mine rarely needs only one kind of survey. It needs detailed static documentation, rapid coverage of changing production areas, and continuous observation of critical zones. *RIEGL* terrestrial laser scanners can address all three requirements with the same platform. For mine operators, that means a single sensor technology can serve in conventional surveying, mobile mapping, and long-term autonomous monitoring while maintaining a consistent data framework (Fig. 3).

The comparison between LiDAR, radar, and total station monitoring also becomes clearer when seen from an operational perspective rather than as a simple technical ranking. Total stations excel where a mine wants exact displacement values at selected critical points, but the information remains limited to those points. Radar delivers broad-area sensitivity to small line-of-sight movements. LiDAR's role is different: it connects monitoring to geometry. Because the entire visible surface is measured in 3D, the mine gains a model that supports not only deformation detection but also topographic interpretation, volumetric comparison, and mine design assessment. In practice, that means LiDAR often contributes both to geotechnical surveillance and to broader survey and planning tasks, which improves the overall return on the system.

standard surveying mobile mapping monitoring

Figure 3: One measurement system for different operating modes.

In the static mode, the scanner is deployed as a high-precision surveying instrument from tripod positions or comparable fixed setups. This remains essential for baseline documentation before excavation or blasting, topographic mapping, stockpile volume determination, fracture and slope analysis, and design verification. Because the system measures dense point clouds over full surfaces, the result is not just a set of geodetic points but a detailed three-dimensional representation of mine terrain and infrastructure. In many mining situations, this is the reference dataset from which later comparisons and operational decisions are derived.

A second mode is kinematic operation. When mounted on a pickup truck or another utility vehicle, the scanner becomes a mobile mapping tool capable of recording large mining areas while the vehicle is moving. For haul roads, pit benches, dumps, berms, tailings structures, and other extensive assets, this operating mode changes the economics of data capture. Large areas can be documented quickly, and survey personnel can remain inside the vehicle rather than entering exposed or traffic-intensive zones. Integrated GNSS and IMU data support georeferencing, and the resulting datasets can be processed into the same spatial environment used for static scans (Appendix 3 – Kinematic App). The benefit for mining operations is straightforward: higher spatial coverage, lower exposure of personnel, and more frequent updating of fast-changing zones without interrupting production.

The third mode, and the one with the greatest impact on geotechnical monitoring, is permanent installation. In this configuration, the scanner is mounted at a fixed location on a mast, concrete base, or protected station (Appendix 4 – Protective Housing) and acquires data automatically at defined intervals. This setup is especially suited to highwall sections, unstable slopes, tailings dams, dump faces, and other critical areas where continuous observation is required. Instead of dispatching personnel repeatedly to carry out field measurements, the monitoring system operates on schedule, processes results automatically, and makes them available remotely.

A key advantage of this permanent mode is that the scanner remains part of a broader operational infrastructure. Through the *RIEGL* CB23 Communication Box, remote access can be established via LTE, Starlink, Wi-Fi, or comparable communication channels (Appendix 5 – *RIEGL* Communication Box CB23). Environmental sensors for temperature, humidity, and air pressure provide the basis for atmospheric corrections. A hardware watchdog supports resilient long-term operation by monitoring system health and restarting components if necessary. In practical terms, the mine gains a monitoring node that is designed for autonomous service in harsh environments.

This permanent setup also creates an important operational benefit that is often overlooked: continuity does not have to mean immobility. In many mines, the same scanner may be required for additional survey tasks beyond its role in a monitoring station. The *RIEGL* monitoring workflow allows the system to be removed temporarily for other jobs and later reinstalled, with automatic re-alignment compensating for offsets and orientation changes. That preserves consistency in the monitoring time series while giving operations more flexibility in asset utilization. Instead of locking equipment into a single-purpose function, the scanner remains adaptable to changing mine requirements.

This ability to preserve the monitoring series after temporary interruption is important for real mine operations. Equipment may need to be inspected, maintained, moved for priority survey tasks, or re-installed after site changes. Automatic re-alignment reduces the risk that such operational realities break the continuity of the monitoring record.

> ***Interview:***
> *Q: Was it useful that the same scanner could be removed for other survey tasks and then returned to monitoring?*
>
> *A: It's always good when a piece of surveying equipment can fulfill multiple roles onsite. There are times when monitoring is the priority, and there are other times when the survey team needs additional data collection elsewhere in the pit. Being able to take the scanner out, use it for a separate survey task, and then bring it back without rebuilding the entire monitoring workflow made the system easier to integrate into our current workflows. In the trial, the process gave us enough confidence that the monitoring results could remain consistent while the instrument could also be used for additional survey work within the mine site.*

3 Autonomous 3D Monitoring with *RIEGL* Monitor+ App as Part of Mine Risk Management

For mining companies under constant pressure to improve productivity and reduce exposure, these three operating modes form a practical bridge between conventional surveying and digital operations. Static surveys provide precise reference models. Mobile mapping captures broad areas efficiently. Permanent installations deliver the temporal density required for geotechnical surveillance. Because all three modes rely on the same underlying sensor logic, mines can combine them into a coherent monitoring concept rather than a collection of disconnected measurement campaigns.

The real transformation begins when LiDAR data acquisition is linked with autonomous processing and operational decision support. In that context, the Monitor+ App is not just an add-on for the scanner. It is the software environment that turns the instrument into an autonomous monitoring platform. Developed for the VZ-i series, it combines monitoring, design comparison, slope analysis, and prism observation within one application environment and allows the complete workflow to run directly on the scanner.

3.1 Site Requirements, Configuration and Scheduling

For mine operators, the first important step is configuration. Users define areas of interest, scan patterns, monitoring intervals, thresholds for change detection, and, if required, the scanning of corner cube prisms. From that point onward, the monitoring sequence can operate autonomously. The scanner acquires data on schedule, processes it onboard, and publishes results without the need for manual intervention. This matters in mining because the critical value of monitoring does not lie in owning data somewhere on a hard drive. It lies in having interpretable information available when operational conditions change. Automatic alignment rules are established for cases in which the scanner is temporarily removed from its monitoring position and needed for other data acquisition tasks. This step matters because it translates site-specific monitoring requirements into a repeatable operational routine. In practice, it reduces dependence on ad hoc field procedures and helps ensure that monitoring remains consistent across long time periods and across changing operational demands.

This configuration phase is where geotechnical intent becomes an operational routine. Areas of interest, surface-monitoring tasks, target-monitoring tasks, alignment rules, epoch adjustment, and schedules are not independent settings; together they define how the monitoring station will behave when no operator is present at the scanner (Appendix 6 – Monitor+ App configuration Wizard).

3.2 On-Sensor Data Model and SPRAW Representation

A particularly distinctive element of the Monitor+ App is the way it handles data internally. Instead of relying on the repeated transfer and comparison of full point clouds in an external office workflow, the scanner transforms the measured data into an image-based representation of the 3D scene. The distance information is encoded with millimeter resolution in the RGB channels of an image, while the local surface normal is stored in the alpha channel. This creates a compact but information-rich model of each monitoring epoch. Because every pixel corresponds to a defined direction in the sensor's polar space, comparisons between epochs can be carried out efficiently at pixel level. The computational advantage is substantial, but the geotechnical advantage is even more important: the app derives change along the local surface normal, which is often more meaningful for slope and surface analysis than a simple line-of-sight displacement measure. (Appendix 7 – SPRAW Image)

The practical consequence is that large monitoring projects can be evaluated without repeatedly moving full raw point clouds through an external office workflow. Each epoch is stored in a structured, direction-based image model that preserves the relevant range and surface-normal information while remaining compact enough for efficient comparison and web-based publication.

3.3 Epoch Comparison, Web Viewer and Cluster Analysis

Epoch Comparison, Web Viewer and Cluster Analysis enable near-real-time change detection. Differences between epochs can be visualized immediately, reference scans can be selected, and thresholds can be applied to distinguish relevant changes from acceptable noise or tolerance ranges. The results are accessed through a web-based viewer that runs directly from the scanner or can be synchronized to a local or cloud-based web server. Users can review monitoring epochs, inspect deformation zones, define custom polygons, evaluate mass balances, and analyze changes over time without relying on external desktop software (Appendix 8 – *RIEGL* Monitor+ Web-Viewer). For mine sites that require broad organizational access to monitoring information, this is a significant operational benefit. Geotechnical teams, planners, and responsible managers can work from the same current information base through an ordinary web browser.

For a mine risk-management workflow, the speed of this comparison is essential. The value of the monitoring system increases when change information is available close to the acquisition time and can be interpreted by the responsible teams before field decisions, exclusion zones, or operational plans have already moved on.

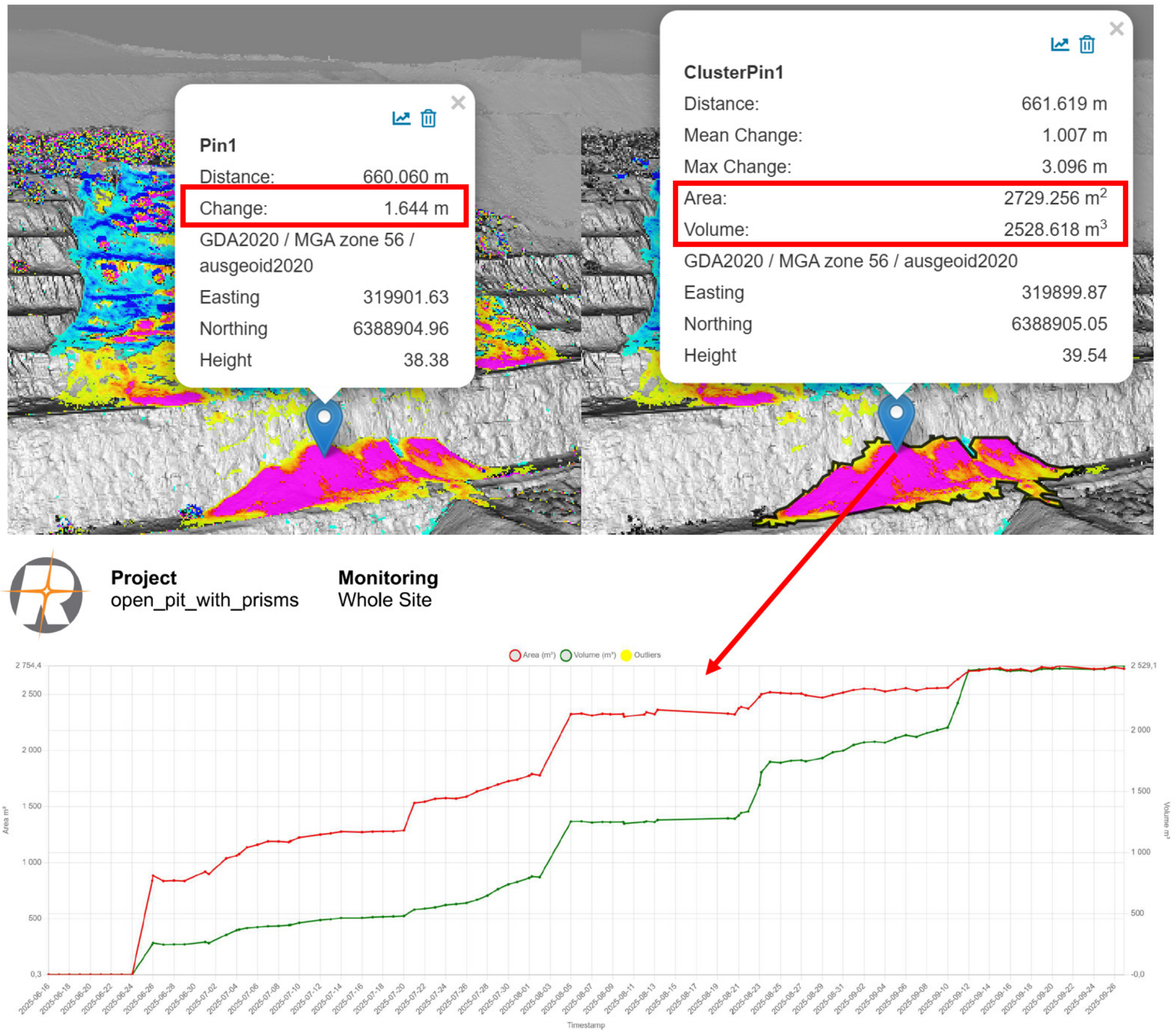
3.4 Cluster-Based Interpretation of Spatial Change

Cluster analysis adds a further layer of value. Rather than treating every changed pixel as a separate observation, the system identifies coherent zones of deformation and calculates relevant metrics such as area and volume. That supports the interpretation of spatial processes in a way that raw difference images alone cannot provide. It becomes possible to distinguish isolated artefacts from meaningful movement zones, to understand whether a change is spreading, and to quantify the affected material. In mining terms, that improves the practical usefulness of the monitoring output. Engineers do not only see that something has changed; they see where the change is clustered, how extensive it is, and how it develops from one epoch to the next (Fig. 4).

Cluster-based evaluation also supports more meaningful threshold concepts. Instead of reacting only to single-pixel exceedances, a site can consider whether a coherent area has grown, whether the accumulated volume has changed, or whether a movement zone is spreading toward infrastructure or active working areas.

> ***Interview:***
> *Q: How did your team use the web viewer and cluster results when reviewing changes between epochs?*
>
> *A: The web viewer allowed multiple stakeholders easy access to the monitoring data without the need to be trained in complex analysis software. The cluster view enabled stakeholders to easily interpret real movement data because it grouped changes into areas that could be judged as geotechnical features rather than just measurement points. We could look at the extent, volume, and development over time, then compare that*

> *with what we knew from the pit: recent blasting, rainfall, haul road activity, or known geological structures. That made the conversation around material movement more practical. It did not replace engineering interpretation, but it gave us a better starting point and reduced the time spent explaining raw data.*



Pin1
Distance: 660.060 m
Change: 1.644 m
GDA2020 / MGA zone 56 / ausgeoid2020
Easting 319901.63
Northing 6388904.96
Height 38.38

ClusterPin1
Distance: 661.619 m
Mean Change: 1.007 m
Max Change: 3.096 m
Area: 2729.256 m^2
Volume: 2528.618 m^3
GDA2020 / MGA zone 56 / ausgeoid2020
Easting 319899.87
Northing 6388905.05
Height 39.54

Project
open_pit_with_prisms

Monitoring
Whole Site

Figure 4: upper left – single pixel analysis shows „Change“ between 2 epochs
upper right – cluster analysis shows „Area, Volume“ between 2 epochs
bottom – diagram of cluster change over all epochs

3.5 Design Comparison, Slope Angle and Extended Analysis Functions

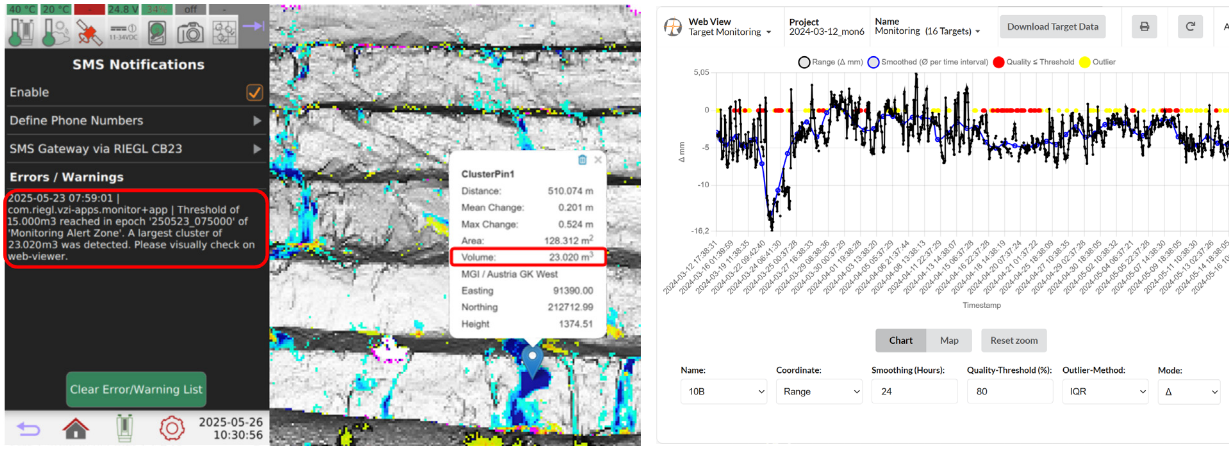
The same integrated logic applies to additional analysis functions. Design comparison enables the mine to check whether the actual geometry of a slope, wall, or engineered structure still matches the intended layout. Slope angle analysis adds another layer of operational relevance by showing whether local gradients are within expected limits or whether deviations are developing that could indicate increased risk. Because these functions are handled within the same application environment, the scanner is not limited to reporting raw change. It becomes a tool for comparing reality with design intent and with geotechnical expectations. For mining operations that must balance safety, compliance, and productivity, that unification of functions reduces workflow fragmentation.

The data web-viewer itself is designed around the practical needs of monitoring users. Different epochs can be opened and compared, reference scans can be assigned, and user-defined zones can be tracked over time. Pixel-based observations can be pinned to create trends, while cluster-based evaluation supports the analysis of coherent movement areas. These functions are not separate office products that need to be assembled manually after each campaign. They are part of an operational workflow intended for repeated use in an active mine environment, where time between acquisition and interpretation is often critical.

3.6 Prism Monitoring, Notifications and Alarm Chains

The Monitor+ workflow also goes beyond a simple comparison of surfaces. It includes built-in prism monitoring, with reflective prisms detected automatically within the scan area and measured according to the defined schedule. Prism positions can be stored as CSV data for external evaluation, while the web viewer supports trend plots of change and speed for individual targets. At the same time, threshold-based notifications can be issued via SMS or email when defined displacement levels are exceeded (Fig. 5). This creates a direct connection between measurement, interpretation, and communication. Together with web-based access to current and historic epochs, custom zone tracking, and synchronization of processed results to local or cloud-based servers, the system supports a monitoring environment in which relevant information can move quickly from the scanner to geotechnical teams, planners, and operational decision-makers.

In this combined concept, prism observations and dense surface monitoring are not competing outputs. They provide different levels of evidence within the same monitoring environment: precise time series at selected points and spatially complete context across the visible surface.



Enable ☑

2025-05-23 07:59:01 | com.riegl.vzi-apps.monitor+app | Threshold of 15.000m3 reached in epoch '250523_075000' of 'Monitoring Alert Zone'. A largest cluster of 23.020m3 was detected. Please visually check on web-viewer.

2025-05-26 10:30:56

Distance: 510.074 m
Mean Change: 0.201 m
Max Change: 0.524 m
Area: 128.312 m²
Volume: 23.020 m³
MGI / Austria GK West
Easting 91390.00
Northing 212712.99
Height 1374.51

Project 2024-03-12_mon6
Name Monitoring (16 Targets)

Name: 10B
Coordinate: Range
Smoothing (Hours): 24
Quality-Threshold (%): 80
Outlier-Method: IQR
Mode: Δ

SMS Notification and Visual Change Detection

Prism Monitoring via Trend Plot

Figure 5: Automatic notifications and visualization of prism monitoring

3.7 Data Handling, Communication and System Resilience

Permanent monitoring also depends on robust data handling. A mine may run a monitoring system for months or years, generating a long sequence of epochs. The compact image-based representation used by the Monitor+ App is therefore important not only for fast processing but also for practical data management. Processed results can be synchronized automatically to local servers, network-attached storage, or cloud-connected environments, while the much larger raw scan data can be retained where required, for example after alarms or special events. (Appendix 9 – Mounting a NAS and RSYNC)

A long-running monitoring installation therefore has to be planned as a data system, not only as a measurement system. Processed results, selected raw data, logs, environmental observations, and alarm-relevant outputs must be stored and synchronized in a way that remains usable after months or years of repeated epochs.

Communication reliability is equally important. A monitoring node installed on a pit rim, a dump crest, or near a tailings facility must continue operating even when local access is difficult. Secure remote communication through LTE, Wi-Fi, or satellite-supported links allows configuration, status checks, and data retrieval without repeated site visits. VPN-secured access supports cyber-safe operation, while the hardware watchdog helps restore service automatically if components fail or require rebooting. In day-to-day mining practice, these details are not secondary. They determine whether an autonomous monitoring station remains a dependable part of the safety infrastructure or becomes a field device that still demands constant attention.

4 Decision Integration and Mine Risk Management

The broader contribution to mine risk management follows directly from that reliability. A monitoring system is valuable only when it can be integrated into alarm chains, control rooms, and decision processes. Threshold-based notifications can be sent automatically by the scanner via the available communication channels (LTE, Wi-Fi, StarLink). This allows the mine to define when a change becomes operationally relevant and who should be informed. That may involve geotechnical engineers, shift supervisors, planners, or emergency response structures, depending on the site. Because the Monitor+ App processes and publishes results onboard, the delay between acquisition and communication is reduced. This strengthens the mine's ability to react early, before an observed pattern escalates into an incident that affects safety or production.

For geotechnical teams, the long-term value of such a system extends beyond immediate alerts. Repeated 3D monitoring epochs provide a time-resolved record of how a surface evolves. That record supports the differentiation between short-term fluctuations and persistent trends, between local disturbances and broader instability, and between expected operational change and abnormal deformation. It also offers a strong basis for comparing observed behavior with geotechnical models and for refining those models over time. In this sense, autonomous LiDAR monitoring is not only a warning tool. It is also a knowledge-building tool that helps mines understand the physical behavior of their assets more comprehensively.

The same history can also be used to check and refine geotechnical assumptions. If monitored behavior agrees with the expected model, confidence in the interpretation increases. If it diverges, the repeated 3D record provides evidence for reassessing the model, the thresholds, or the operational response strategy.

> ***Interview:***
> *Q: What did the repeated 3D epochs add compared with looking only at alarms or single measurements?*
>
> *A: The repeated epochs gave us a record of behavior, not just a list of events. In a mine, a small movement is not automatically a problem, and a quiet period is not automatically safe. What matters is whether the pattern is changing, spreading, accelerating, or matching what the geotechnical model suggests. With the 3D surface history, we could go back and see how a bench, wall, or dump face had evolved over several monitoring cycles. That helped us separate short-lived surface disturbance from more persistent deformation. It also gave the geotechnical team better data for discussions with planning and operations, because we were not relying only on isolated values.*

This is also where the broader strategic value becomes clear. LiDAR does not replace any other monitoring technology, nor should it be framed that way. In large mines, the most robust strategy often combines prism monitoring for highly precise control points, radar for wide-area displacement detection, and LiDAR for dense 3D surface understanding. Yet within that multi-sensor environment, autonomous terrestrial laser scanning contributes a capability that is difficult to reproduce otherwise: it provides spatially complete geometry, repeated at useful intervals, with direct onboard processing and intuitive web-based access. That makes it particularly effective for identifying not only whether movement is occurring, but how it is distributed across the monitored structure.

Another practical strength is that the scanner ecosystem fits into a mine's existing technical landscape instead of standing apart from it. The open architecture of the VZ-i series allows custom applications in Python or C++, enabling integration into local control-room infrastructure, alarm chains, messaging systems, storage environments, and project-specific workflows. Processed results can be published through the scanner's own web server or synchronized automatically to other servers. This supports a monitoring concept in which the scanner is not an isolated measurement device, but a connected component within the digital backbone of the operation.

That broader integration matters because geotechnical monitoring ultimately succeeds only when information reaches the right people in time and in a form they can use. A dense 3D surface record is valuable for specialists, but it becomes operationally decisive when it is paired with alerting, visualization, and a workflow that reduces manual intervention. The combination of web-based access, autonomous processing, and consistent measurement geometry therefore has implications beyond survey efficiency. It improves the ability of mines to standardize monitoring practice across different sites, different structures, and different stages of the mining cycle while keeping the underlying data logic consistent.

> ***Interview:***
> *Q: Did the system make monitoring information easier to share with operational teams?*
>
> *A: Being able to log into a web URL enabled multiple stakeholders to review the data at any given time. During the trial the web access and automated outputs made it easier to bring the same information into discussions with geotechnical engineers, survey, planning, and operations. We could point to the same current view instead of sending screenshots around or waiting for a separate processing step. The alerting concept was also useful because it connected defined site TARP thresholds with real-time communication, rather than relying entirely on someone manually checking every dataset and then being a delay in receiving results.*

For the mining industry, the implications are practical rather than abstract. Safer decisions depend on faster recognition of relevant changes. More efficient operations depend on reducing unnecessary field exposure and on using the same sensor platform for multiple tasks. Better planning depends on having data that describes both the current state of the mine and its evolution over time. By combining flexible deployment, onboard processing, cluster-based interpretation, and integration into communication and alerting workflows, the *RIEGL* scanner ecosystem supports exactly that type of informed, digital mine management.

The direction of travel is clear. As mines continue to digitalize, demand will grow for monitoring systems that do more than collect data. They will be expected to interpret change, communicate relevance, and fit naturally into operational decision structures. Autonomous LiDAR systems equipped with application environments such as the Monitor+ App already point toward that future. They do so not through broad promises, but through a specific combination of long-range measurement performance, operational flexibility, and edge-based analysis that is directly aligned with the needs of modern mining.

5 Conclusion and Outlook

Autonomous terrestrial LiDAR monitoring strengthens mine risk management by connecting dense 3D measurement with repeatable analysis and fast communication. Its role is not to replace established monitoring technologies, but to add the geometric context that point-based and line-of-sight systems cannot provide on their own.

The practical value becomes strongest when the scanner is treated as an autonomous analysis node. With the Monitor+ App, acquisition, alignment, pixel-based change computation, cluster evaluation, prism monitoring, web visualization, and notification workflows can be combined in one repeatable process. This reduces manual processing effort and shortens the path from measurement to interpretation.

For future mine operations, this points toward monitoring systems that are increasingly integrated into the digital backbone of the site. LiDAR-derived surface histories can support geotechnical model validation, threshold refinement, design comparison, and transparent communication between survey, geotechnical, planning, and operations teams.

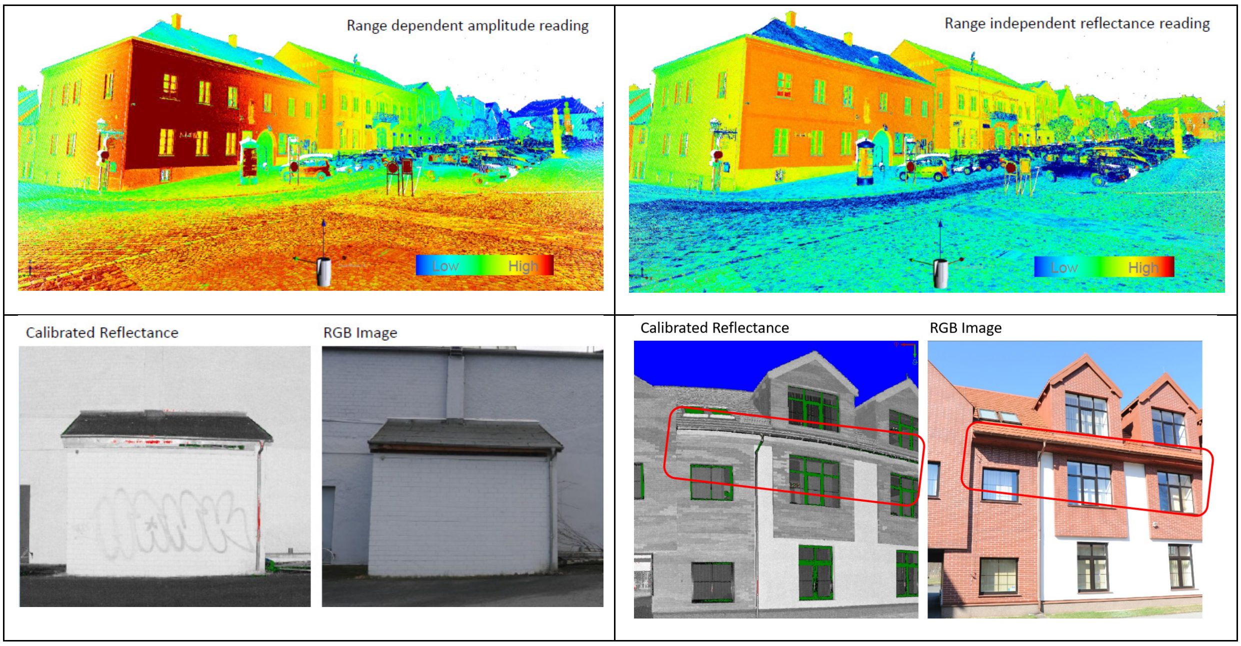
The outlook is therefore not only more automation, but more actionable information. As mines continue to digitalize, autonomous 3D monitoring will become a key component of multi-sensor risk-management strategies: precise enough for technical interpretation, robust enough for field operation, and accessible enough to support timely operational decisions.

Appendix 1 – Additional Attributes beyond X/Y/Z

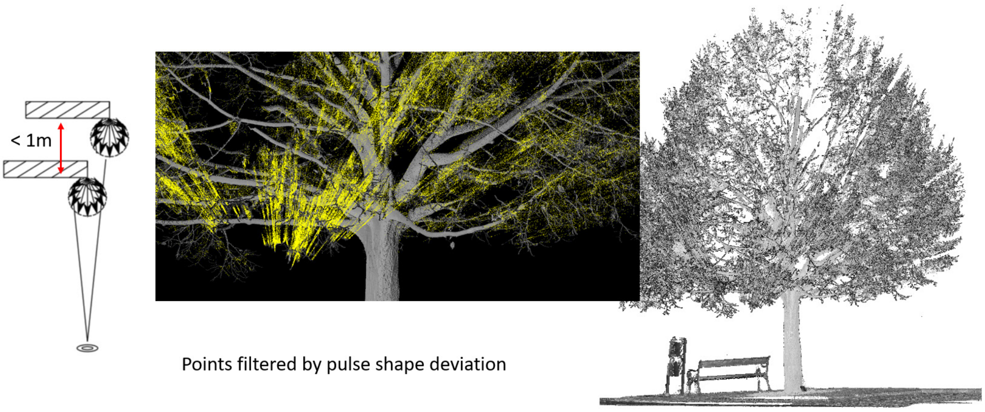
RIEGL laser scan data provides more information than the geometric point coordinates X, Y and Z. In addition to the commonly known intensity attribute, *RIEGL* scanners deliver a set of calibrated and waveform-based attributes that help users assess surface properties, measurement quality and complex target situations.

A key attribute is **calibrated amplitude**. It represents the strength of the received laser echo relative to the scanner’s detection threshold and is expressed on a logarithmic dB scale. Normally this data is simply stored as a 256 ranging value in grey-scale and named Intensity. *RIEGL* keeps the whole range of values and stores it in logarithmic dB scale. Amplitude is useful for visualizing the returned signal strength, but it is strongly range-dependent: identical surfaces appear darker at longer distances because the returned signal becomes weaker with increasing range.

For material-related interpretation, **calibrated reflectance** is more suitable. It describes the ratio between the measured echo amplitude and the expected amplitude of a white, diffusely reflecting target at the same range. As a result, reflectance is largely independent of object distance and enables more reliable comparison of similar surfaces at different ranges. It can reveal surface properties that may not be visible in RGB images, for example differences in moisture, coating, material type or retro-reflective targets.



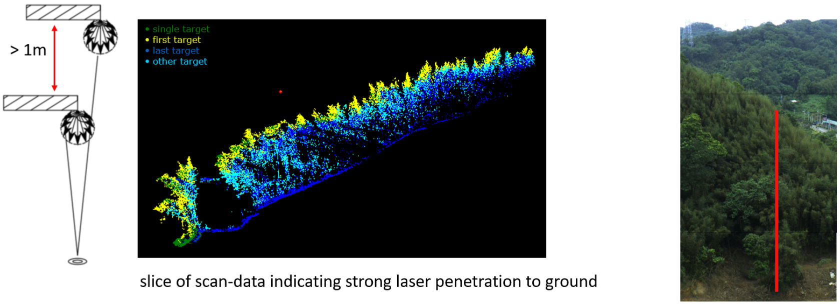
Another important attribute is **pulse shape deviation**. *RIEGL’s* online waveform processing compares the detected echo pulse with an instrument-specific reference pulse. The deviation value indicates how well the measured echo fits the expected pulse shape. Low values usually indicate reliable range measurements, while high values often occur at edges, thin objects, vegetation or mixed target situations where the laser footprint hits more than one surface with range spacing of less than 1 meter. This attribute is therefore highly valuable for quality control and automatic filtering of unreliable points.



Points filtered by pulse shape deviation

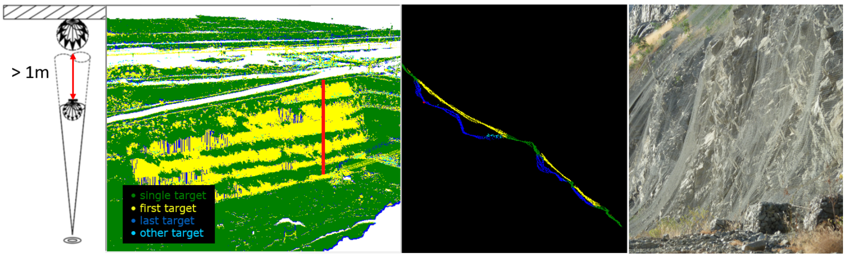
RIEGL scanners can also detect **multiple targets from a single laser shot**. Instead of recording only one return, the system can separate several echoes along the laser path and classify them as single, first, last or other targets (range spacing of more than 1 meter). This capability is especially useful for scanning through vegetation, mesh, dust, rain or snow, where foreground particles or thin structures may only partially intersect the laser beam while surfaces behind them remain detectable.

Multiple Target Capability enables penetration of vegetation



slice of scan-data indicating strong laser penetration to ground

Multiple Target Capability enables penetration of fine meshes



fine-meshes are classified as „first targets"

Finally, external attributes such as **RGB color** or thermal information can be added from integrated sensors. These enrich visual interpretation but should be understood as complementary to the laser-derived attributes. Together, calibrated amplitude, calibrated reflectance, pulse shape deviation and multiple-target information provide an attribute-rich point cloud that supports classification, filtering and a deeper understanding of the measured scene.

[Training Module "Additional Attributes of *RIEGL* Scandata"]

Appendix 2 – MTA (Multiple Time Around) Data Processing

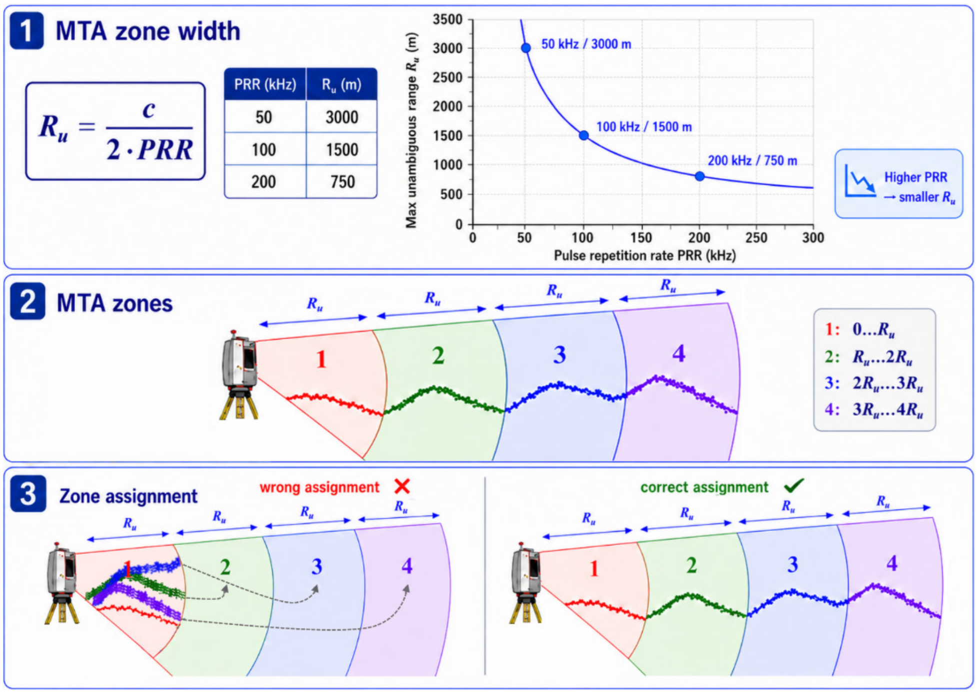
In time-of-flight laser scanning, **MTA (Multiple-Time-Around)** describes a range ambiguity that occurs when the laser pulse repetition rate is so high that the echo from a distant target returns only after one or more subsequent laser pulses have already been emitted. In this case, the scanner measures the time difference between an emitted pulse and a received echo, but it must also determine **which emitted pulse the echo belongs to**.

The size of one MTA zone is defined by the **maximum unambiguous range**:

$$R_u = \frac{c}{2 \cdot PRR}$$

c is the speed of light and *PRR* is the pulse repetition rate. The factor 2 accounts for the two-way travel path of the laser pulse from the scanner to the target and back. For example, a *PRR* of 50 kHz results in an MTA-zone width of about 3000 m, 100 kHz gives about 1500 m, and 200 kHz gives about 750 m. Higher pulse repetition rates therefore increase the measurement speed and point density, but reduce the unambiguous range interval.

The full distance range is divided into consecutive MTA zones. A measured echo may appear to originate from the first zone, although the real target is located in the second, third, or higher zone. If the MTA zone is assigned incorrectly, the reconstructed range is shifted by one or more MTA-zone widths, which leads to misplaced points and interlacing effects in the point cloud.



[Journal of Applied Remote Sensing: Resolving range ambiguities in high-repetition rate airborne light detection and ranging applications (Rieger, Ullrich)]

To resolve this ambiguity, the scanner does not use a strictly constant time spacing between laser shots. Instead, the sequence of pulse repetition intervals is slightly modulated. For each received echo, several possible range solutions are calculated, one for each possible MTA zone. Over a package of consecutive laser shots, the correct MTA-zone assignment produces a consistent range sequence with the lowest scatter or residual noise. Incorrect MTA-zone assumptions, however, lead to range values that fluctuate more strongly because the small timing modulation affects the wrong candidate solutions inconsistently. The scanner therefore selects the MTA zone with the lowest residual variation and assigns the echo to this zone, allowing the true target distance to be reconstructed even at high repetition rates and long ranges.

Appendix 3 – Kinematic Data Acquisition

Static terrestrial laser scanning and kinematic data acquisition are two complementary methods for capturing high-quality 3D point clouds. In static TLS, the scanner is positioned on a stable setup and records the surrounding environment from fixed scan positions. This approach is ideal when maximum geometric stability, controlled scan geometry, and high-detail acquisition of specific areas are required. Multiple static scans can later be registered and adjusted to create a complete 3D dataset.

Kinematic data acquisition, by contrast, turns the scanner into a mobile mapping system. The scanner is mounted on a moving platform such as a vehicle, backpack, bicycle, or boat and continuously records data while the platform moves through the area of interest. This enables large areas, difficult-to-access zones, road corridors, shorelines, urban environments, and mining sites to be captured in a much shorter time than with conventional static setups.

The key difference lies in positioning and processing. Static TLS relies primarily on the known scanner position at each setup, while kinematic acquisition requires a continuously calculated trajectory. This trajectory is derived from GNSS and IMU observations and can be supported by RTK corrections or post-processed using base station data. After acquisition, the trajectory and laser data are converted and refined, typically using GNSS, IMU, and LiDAR observations, including plane-based matching for improved consistency.

In practical terms, static scanning offers maximum control and is well suited for detailed, station-based surveys. Kinematic acquisition offers much higher productivity and flexibility, especially when continuous coverage over long distances is required. However, it also depends more strongly on GNSS quality, platform motion, suitable acquisition speed, and dedicated processing workflows. For this reason, kinematic scanning is not a replacement for static TLS, but an extension of it: the same scanner can be used either in a static or mobile workflow, depending on the application requirements.

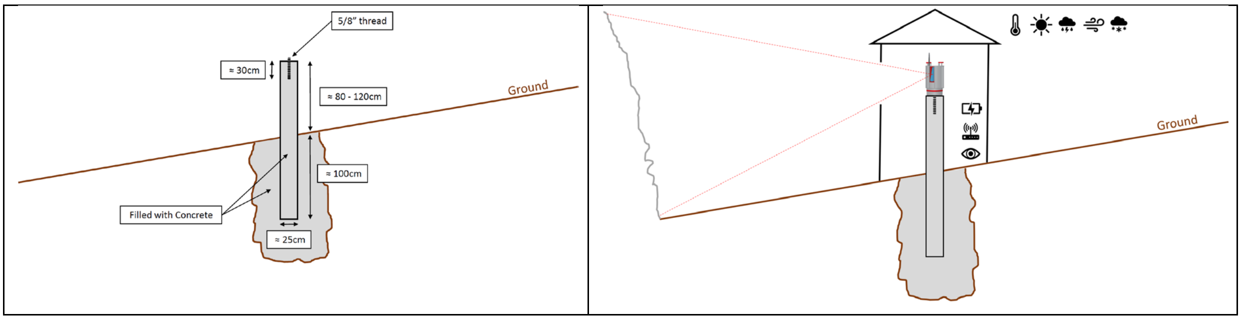
Info Sheet “Kinematic App”

Training Module “*RIEGL* VZ-i Series Kinematic Data Acquisition”

Appendix 4 – Equipment Protection

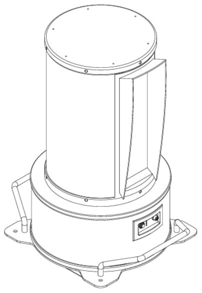
For engineering geodetic surveying tasks, such as deformation measurements, reliable control points are required on which repeated observations are carried out on a continuous schedule. **Surveying pillars** are the most stable way to mark a survey point, if the design meets the technical requirements. A suitable position for a survey pillar demands knowledge of the geological conditions on site. Survey pillars must always be placed outside the area of influence of the construction project. The distance between the survey pillar and the structure to be built depends on its depth and the respective soil type. In any case, the survey pillar must be placed outside the zero line of subsidence.

Another important criterion in the choice of location is the unobstructed view. This ensures that the required clear views are available for monitoring tasks. Optimal locations for survey pillars are those that are naturally higher in the terrain. Again, the geology of the elevation must be considered. In the case of artificially created embankments such as dikes, dams or noise protection structures, it must be agreed with the responsible operating authority whether an excavation of the ground or of the substance is permitted. Taking into account all the above-mentioned criteria, a final concept for the installation of the survey pillars will be drawn up.



A pillar with about 25 cm diameter, for example a PVC pipe, is concreted approximately 100 cm deep into a hole in the ground and filled with concrete. The pillar should rise about 80-120 cm from the ground. In addition, a standard tripod mounting 5/8“ thread is concreted into the top of the pillar to a depth of approx. 30cm, to which the scanner is then screwed. For a permanent installation of the scanner over a long period of time, the system should be protected by a **shelter**. In this way, the devices are not exposed to the weather. There should be no direct connection between the shelter and the concrete pillar on which the scanner is mounted. Vibrations on the shelter caused by wind or other mechanical impacts must not affect the scanner’s mount. In addition, a power supply is required to ensure uninterrupted operation of the scanner, and a stable internet connection is needed for remote control and data synchronization with a server or the cloud. Instead of using a shelter, the scanner can be protected by ***RIEGL*’s “Protective Housing Light”** or—for an even higher IP rating—by the “**Armour Case**” from *RIEGL*’s supplier Syperion.

Infosheet *RIEGL*
Protective Housing Light



Flyer Syperion
Armour Case

Appendix 5 – *RIEGL* Communication Box CB23

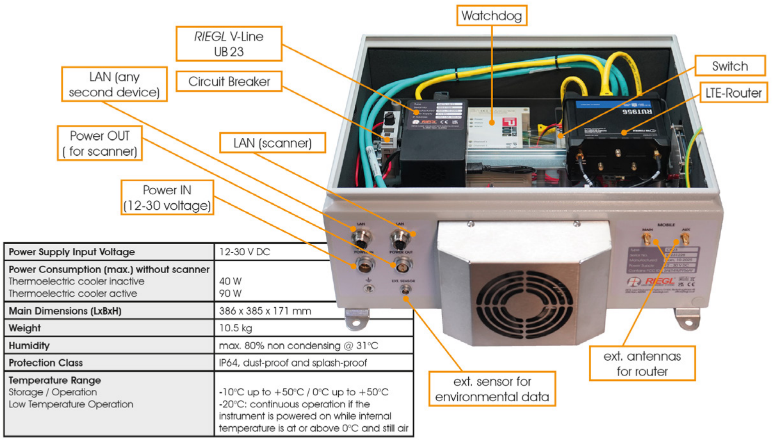
The *RIEGL* V-Line CB23 Communication Box is designed for fixed *RIEGL* V-Line scanner installations, especially in remote or harsh environments where stable power supply, network connectivity, and reliable 24/7 operation are essential. It provides a protected central hardware platform that supplies and connects all relevant components, including the scanner, the integrated UB23 Upgrade Box, router, switch, watchdog, environmental sensors, cooling, dehumidification, and power distribution. The box uses one Power IN connection to support the entire system and provides Power OUT for the scanner. Its IP64-rated housing protects the electronics against dust and splash water, while the integrated thermal management supports operation across a wide temperature range.

A key function of the CB23 is remote accessibility and system resilience. The LTE router enables internet connectivity using a local SIM card (alternatively internet can be also provided by a Starlink connection), while a pre-installed VPN connection protects the system against unauthorized access and allows remote configuration of the integrated hardware. The internal switch manages the TCP/IP connections between scanner, UB23, router, and additional network devices. The watchdog continuously checks connected hardware by sending scheduled pings. If a device does not respond, the watchdog can switch the corresponding power relay to force a reboot, helping the system automatically recover from hardware or firmware problems and continue the defined acquisition tasks.

The integrated *RIEGL* V-Line UB23 is the intelligence layer of the system. It is a compact micro-computer with pre-installed software that brings VZ-i-like functionality to existing *RIEGL* VZ-Series scanners such as the VZ-400, VZ-1000, VZ-2000, VZ-4000, and VZ-6000. It supports automatic data acquisition workflows, automatic scan data registration, onboard processing apps, Python scripting for customization, remote scanner operation, and automatic synchronization of scan data to a NAS Network Attached Storage or cloud storage via network protocols such as SFTP. The graphical user interface is accessed through a VNC viewer, for example via the *RIEGL* VZ-i Series App. The UB23 also manages high-accuracy environmental data. The CB23 integrates one internal sensor for monitoring the box environment and one external sensor with a 3 m cable for measuring ambient temperature, air pressure, and humidity at a representative location near the scanner. These values can be displayed historically via a UB23 webserver and are used for atmospheric correction of the acquired scan data. Together, CB23 and UB23 provide a robust, remotely manageable platform for automated long-term laser scanning installations.

[Infosheet *RIEGL* CB23](#)

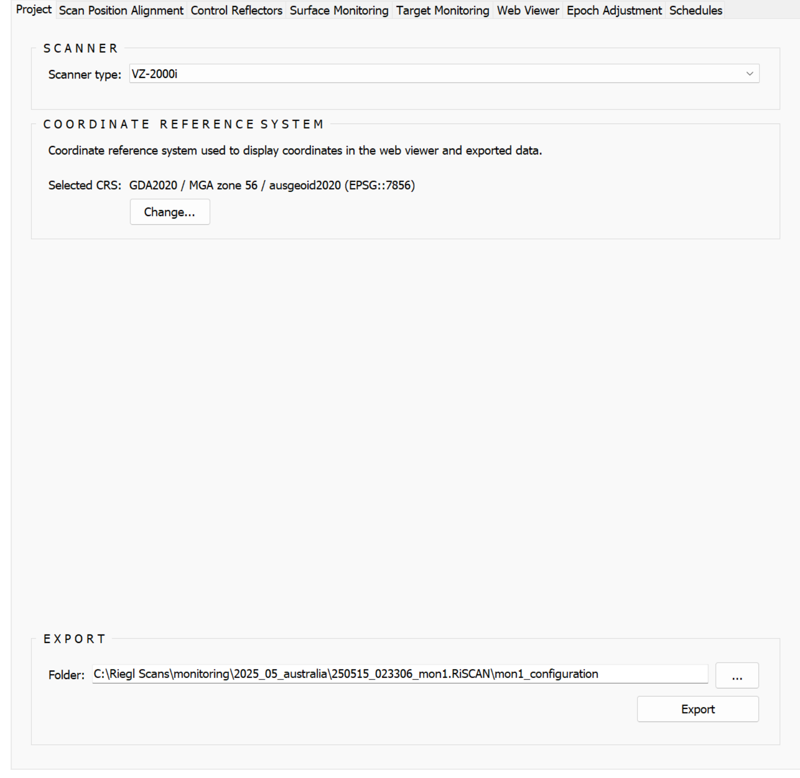
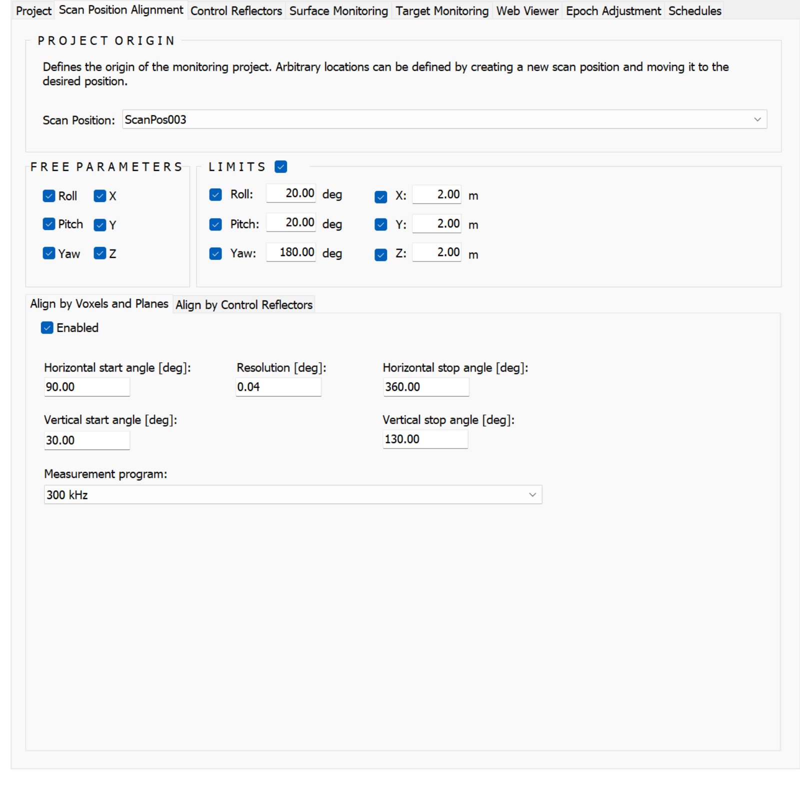
[Infosheet *RIEGL* UB23](#)



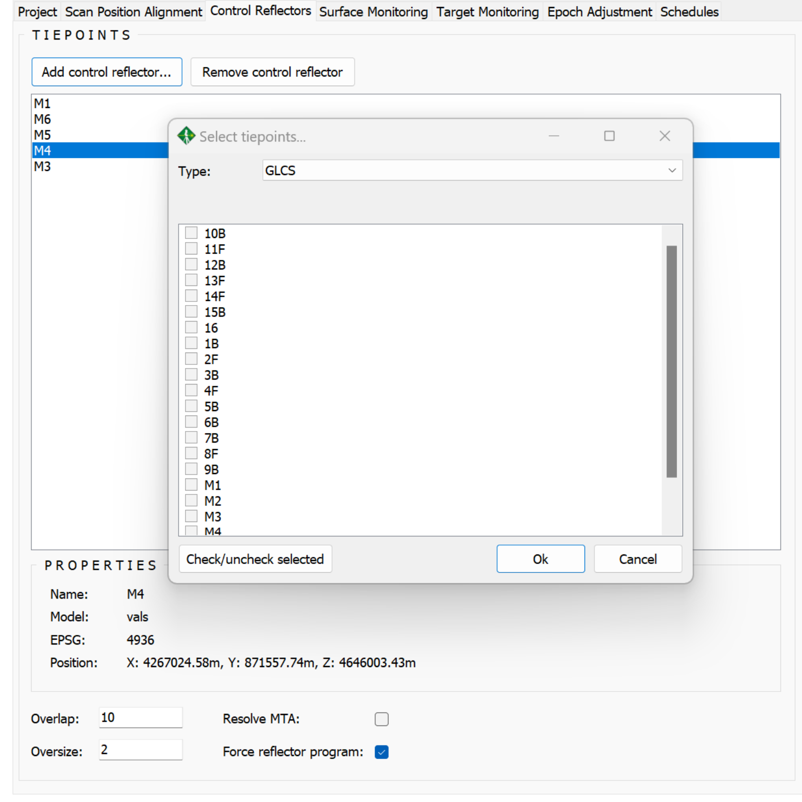
Power Supply Input Voltage	12-30 V DC
Power Consumption (max.) without scanner Thermoelectric cooler inactive Thermoelectric cooler active	40 W 90 W
Main Dimensions (LxBxH)	386 x 385 x 171 mm
Weight	10.5 kg
Humidity	max. 80% non condensing @ 31°C
Protection Class	IP64, dust-proof and splash-proof
Temperature Range Storage / Operation Low Temperature Operation	-10°C up to +50°C / 0°C up to +50°C -20°C: continuous operation if the instrument is powered on while internal temperature is at or above 0°C and still air

Appendix 6 – *RIEGL* Monitor+ App Configuration Wizard

Configuration of the Monitor+ App is realized within *RIEGL's* TLS postprocessing software suite RiSCAN PRO. Starting point is always an existing registered RiSCANPRO project. Following we describe the necessary configuration steps for a complex monitoring campaign, which will finally run fully autonomously on the scanner.

 SCANNER Scanner type: VZ-2000i COORDINATE REFERENCE SYSTEM Coordinate reference system used to display coordinates in the web viewer and exported data. Selected CRS: GDA2020 / MGA zone 56 / ausgeoid2020 (EPSG::7856) EXPORT Folder: C:\Riegl Scans\monitoring\2025_05_australia\250515_023306_mon1.RiSCAN\mon1_configuration	All files necessary for a correct configuration of the Monitor+ App are stored within a single folder. The destination folder is defined here. Finally, this folder has to be copied on the scanner to make it available for the Monitor+ App.
 PROJECT ORIGIN Defines the origin of the monitoring project. Arbitrary locations can be defined by creating a new scan position and moving it to the desired position. Scan Position: ScanPos003 FREE PARAMETERS ☑ Roll ☑ X ☑ Pitch ☑ Y ☑ Yaw ☑ Z LIMITS ☑ ☑ Roll: 20.00 deg ☑ X: 2.00 m ☑ Pitch: 20.00 deg ☑ Y: 2.00 m ☑ Yaw: 180.00 deg ☑ Z: 2.00 m ☑ Enabled Horizontal start angle [deg]: 90.00 Resolution [deg]: 0.04 Horizontal stop angle [deg]: 360.00 Vertical start angle [deg]: 30.00 Vertical stop angle [deg]: 130.00 Measurement program: 300 kHz	The position of the scanner from where the monitoring is performed must be aligned to the project origin. The project origin is defined by an existing registered scan position. Depending on how the scanner will be finally mounted for the monitoring process the user can define free parameters and limits for the alignment calculation. The scanner's position in respect to the project origin should be as close as possible. The alignment can be calculated based on voxels/planes and/or control reflectors. The monitoring can be stopped at any time and the scanner can

be dismounted to be used for other purposes. When the scanner is mounted again later, the alignment procedure is performed before starting further monitoring data acquisition.



M1
M6
M5
M4
M3

Type: GLCS

☐ 10B
☐ 11F
☐ 12B
☐ 13F
☐ 14F
☐ 15B
☐ 16
☐ 1B
☐ 2F
☐ 3B
☐ 4F
☐ 5B
☐ 6B
☐ 7B
☐ 8F
☐ 9B
☐ M1
☐ M2
☐ M3
☐ M4

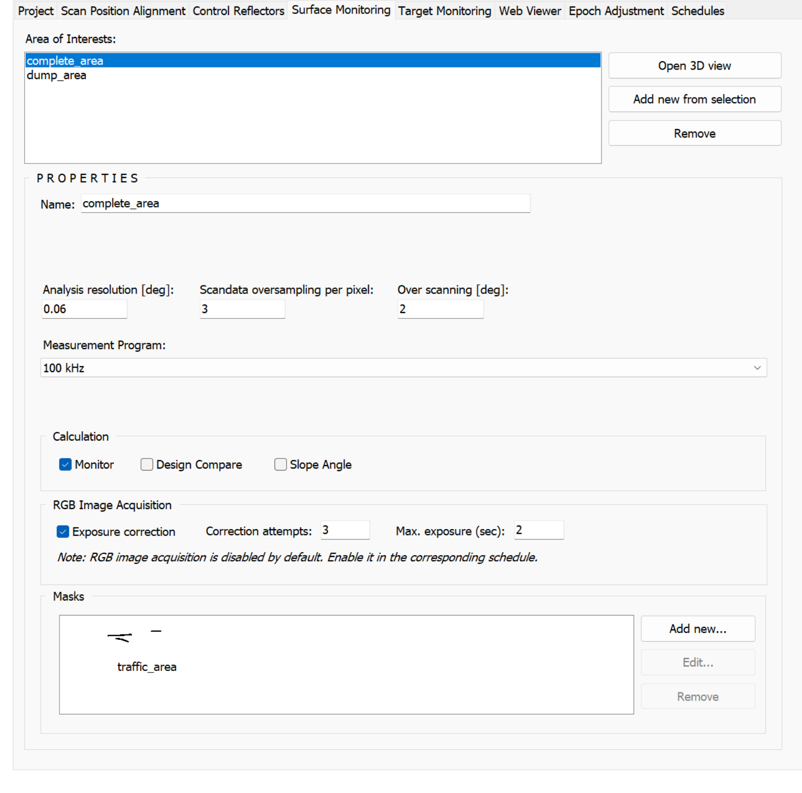
Name: M4
Model: vals
EPSG: 4936
Position: X: 4267024.58m, Y: 871557.74m, Z: 4646003.43m

Overlap: 10
Oversize: 2
Resolve MTA: ☐
Force reflector program: ☑

A set of control reflectors is defined. The source can be any tie point list within the project. Furthermore, settings for fine scanning of the targets are defined. The default value for Overlap is 10, and for Oversize is 2. These values fit for most cases.

In case of fine-scanning prisms it is strongly recommended to enable “force reflector program”, otherwise the center of the prism cannot be detected with highest precision.

Enabling “Resolve MTA” is only mandatory, if the target is further away than MTA zone 1.



Area of Interests:
complete_area
dump_area

Name: complete_area

Analysis resolution [deg]: 0.06
Scandata oversampling per pixel: 3
Over scanning [deg]: 2

Measurement Program: 100 kHz

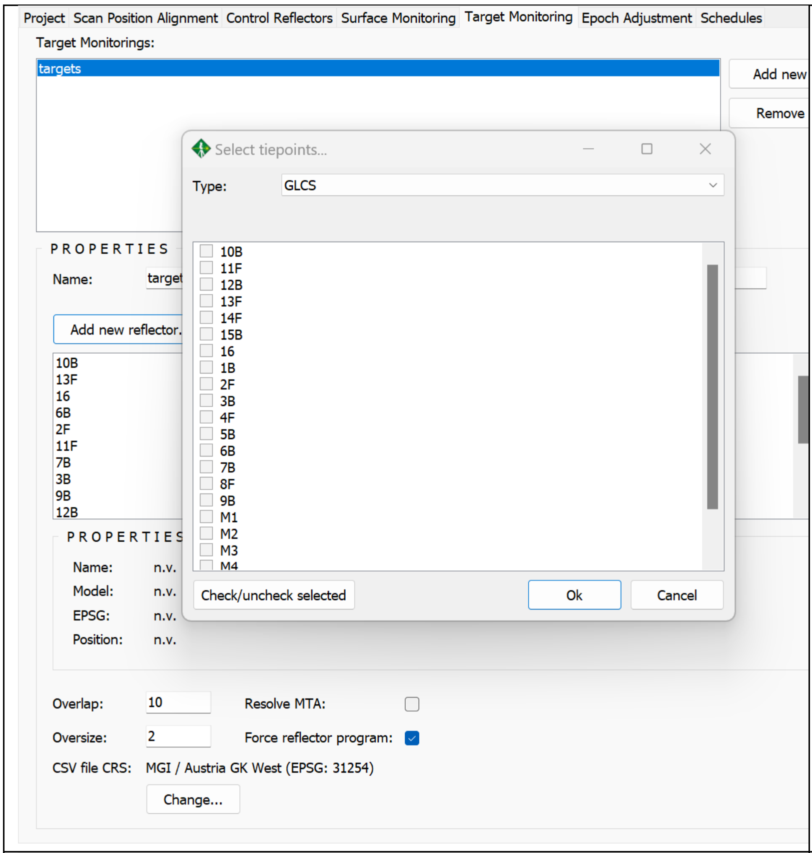
Calculation
☑ Monitor ☐ Design Compare ☐ Slope Angle

RGB Image Acquisition
☑ Exposure correction Correction attempts: 3 Max. exposure (sec): 2

Note: RGB image acquisition is disabled by default. Enable it in the corresponding schedule.

Masks
traffic_area

The calculation-modes for each area of interest are defined (Monitor/DesignCompare/ SlopeAngle). An AoI is defined by clicking the button “Open 3D view”, which opens the scan data of the scan position defined as project’s origin. Now the desired area is selected on the scan data within the 3D view. By clicking on “Add new from selection” a new AoI is defined. A number of different AoIs can be defined. Angular resolution and measurement program of the scan are defined in the lower section. RGB image acquisition can be enabled. Masks of areas, which should be excluded from calculation, can be defined.



Target Monitorings: targets

Select tiepoints...

Type: GLCS

☐ 10B
☐ 11F
☐ 12B
☐ 13F
☐ 14F
☐ 15B
☐ 16
☐ 1B
☐ 2F
☐ 3B
☐ 4F
☐ 5B
☐ 6B
☐ 7B
☐ 8F
☐ 9B
☐ M1
☐ M2
☐ M3
☐ M4

PROPERTIES

Name: target

10B
13F
16
6B
2F
11F
7B
3B
9B
12B

PROPERTIES

Name: n.v.
Model: n.v.
EPSG: n.v.
Position: n.v.

Overlap: 10
Oversize: 2
Resolve MTA: ☐
Force reflector program: ☑
CSV file CRS: MGI / Austria GK West (EPSG: 31254)

Sets of targets to be monitored are defined. Different sub-sets of targets for monitoring can also be defined. That makes sense if these subsets should be finally monitored by using different schedules. The lower section again defines the settings for fine scanning the targets. Finally, the Monitor+ App on the scanner creates a CSV text file for each data acquisition epoch, containing the coordinates of the targets in a defined CRS system.

MONITORING

Below Reference: Blue, None; - 0.5, - 0.03
Above Reference: None, Fuchsia; 0.03, 0.5

SLOPE ANGLE

Angle degrees: None, Red; 0.03, 0.5

DESIGN COMPARISON

Below Reference: Blue, None; - 0.5, - 0.03
Above Reference: None, Red; 0.03, 0.5

Polydata model to compare against: None

TARGET MONITORING

Background image: None

Default threshold values and color tables for the visualization of the different calculation modes within the web-viewer are defined.

FREE PARAMETERS

☑ Roll ☑ X
☑ Pitch ☑ Y
☑ Yaw ☑ Z

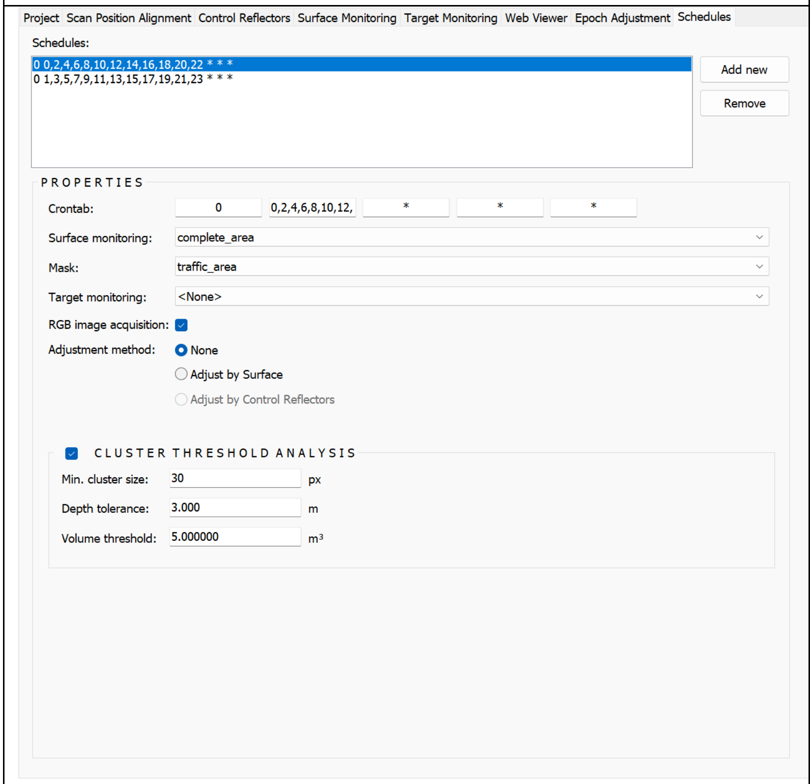
LIMITS ☑

☑ Roll: 5.00 deg ☑ X: 0.10 m
☑ Pitch: 5.00 deg ☑ Y: 0.10 m
☑ Yaw: 5.00 deg ☑ Z: 0.10 m

ADJUSTMENT

☑ Adjust by Surface Scenario: Read from project
☐ Adjust by Control Reflectors

Epoch adjustment works similar as scan position alignment. It is applied on every new data acquisition epoch and adjusts minor movements of the scanner caused by instabilities of the mounting platform. A reason for such a movement can be a temperature increase on the mounting platform from one side caused by direct sun light. Epoch adjustment can be calculated based on planes (adjusted by surface) or based on control reflectors.



Schedules:
0 0,2,4,6,8,10,12,14,16,18,20,22 * * *
0 1,3,5,7,9,11,13,15,17,19,21,23 * * *

PROPERTIES

Crontab: 0 | 0,2,4,6,8,10,12, | * | * | *
Surface monitoring: complete_area
Mask: traffic_area
Target monitoring: <None>
RGB image acquisition: ☑
Adjustment method: ● None
○ Adjust by Surface
○ Adjust by Control Reflectors

☑ CLUSTER THRESHOLD ANALYSIS

Min. cluster size: 30 px
Depth tolerance: 3.000 m
Volume threshold: 5.000000 m^3

Schedules are defined based on the crontab syntax.

https://en.wikipedia.org/wiki/Cron

For every schedule an AoI from “Surface Monitoring” and/or a target set from “Target Monitoring” can be selected. Image acquisition and epoch adjustment method can be activated. On enabling “Cluster Threshold Analysis” the scanner is forced to send an SMS alarm on reaching the volume threshold value.

Once all settings are defined, jump back to page one and press the “Export” button. Copy the exported folder on the scanner and start the Monitor+ App.

TLS Training Module - V-Line Monitor+ App

Appendix 7 – Data Format SPRAW (Scan Patch RAW) Image

For the visualization of changes between two data sets acquired at two different times (epochs), the *RIEGL* scan data is converted into 2D data sets (image in PNG format) and finally compared against each other.

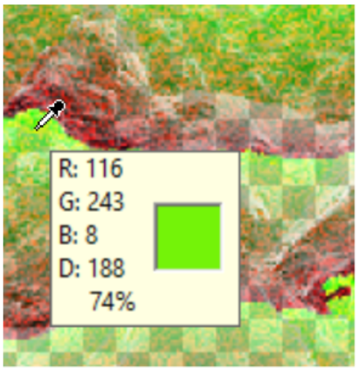
The range value of each scene is stored as RGB value (see formula below).

$$Range\ (m) = (Red + 256 * Green + 256^2 * Blue) * 0.001$$

$$(116 + 256 * 243 + 256^2 * 8) * 0.001$$

$$=$$

$$586{,}612\text{m}$$

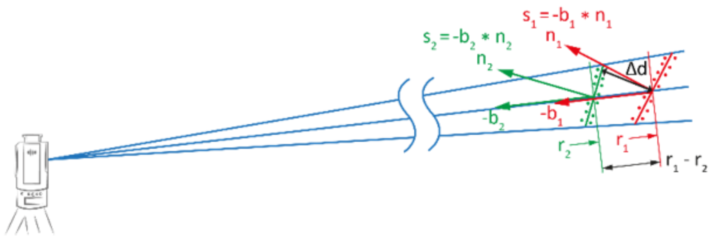


The RGB range coding allows range values with millimeter resolution over more than 16 km range, which is much further than any laser scanner can measure. The local surface normal vector information is stored in the alpha channel of the image. The scalar product (a value between 0 and 1) between the local normal vector and the laser beam direction is calculated. In case the surface normal vector is equal to the negative beam direction (we look perpendicular towards the surface), the scalar product is 1, which results in a value of 255 in the alpha channel. The more the surface normal is tilted against the beam direction the lower the alpha value. The following formula is used to calculate the local differences of each image pixel.

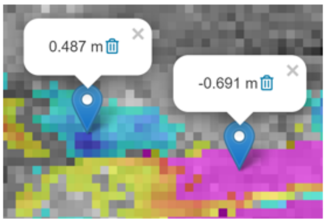
$$\Delta d = (r1 - r2) * \frac{s1 + s2}{2}$$

r1…range value of comparison data set
r2…range value of reference
s1…scalar product of comparison data set
s2…scalar product of reference

The resulting change in range is change along the average normal vector of the two pixels (reference, comparison data set). Positive values are indicating longer range (material erosion), while negative values are indicating shorter range (material accumulation).



graphical explanation of the formula

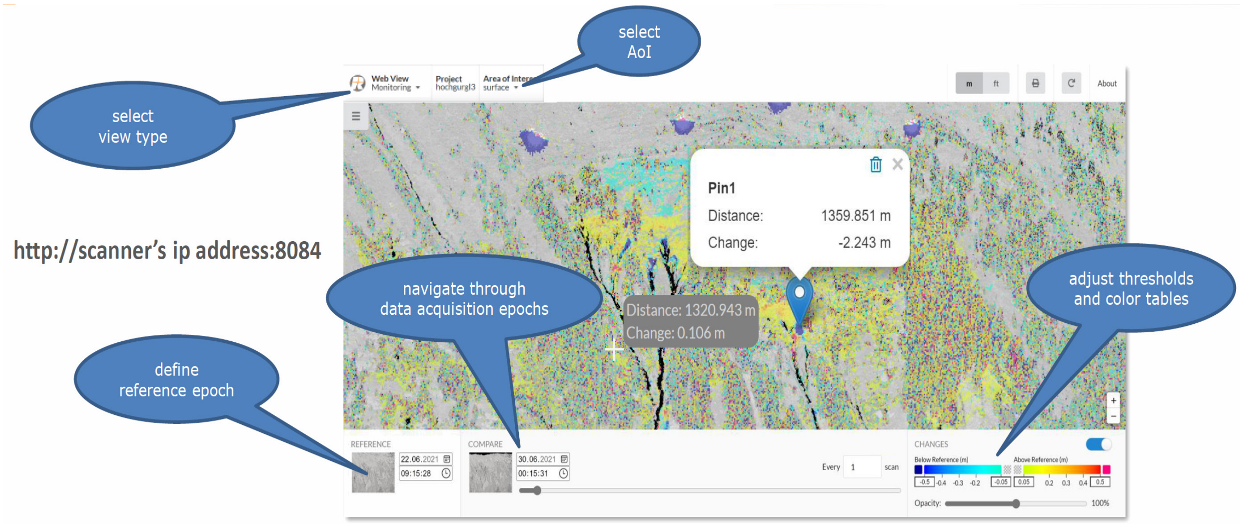


result of formula visualized in web viewer

Appendix 8 – *RIEGL* Monitor+ Web-Viewer

The *RIEGL* Monitor+ Web Viewer is the browser-based analysis interface for monitoring projects acquired with the Monitor+ App on *RIEG*L VZ-i Series scanners. It provides direct access to processed monitoring results via the scanner's web server and allows users to navigate through projects, areas of interest, and individual acquisition epochs. The viewer visualizes surface change by comparing a selected monitoring epoch with a defined reference epoch. Users can move the cursor over the image to read distance and change values, set markers, zoom into areas of interest, and adjust thresholds, color tables, and opacity for detailed interpretation.

Different background representations - such as reflectance, shaded relief, or panorama images - support visual orientation. For advanced analysis, the viewer includes cluster detection, where neighboring cells with similar change direction are grouped to derive area and volume information. Polygon-based selection enables mass-balance inspection within user-defined regions. In addition to surface monitoring, the Web Viewer supports target monitoring with chart and map views, including smoothing, outlier filtering, and change or speed visualization. Further view modes include slope-angle analysis and design comparison. Export, import, statistics, and print functions help document, reproduce, and share monitoring results efficiently.



Pin1
Distance: 1359.851 m
Change: -2.243 m

Distance: 1320.943 m
Change: 0.106 m

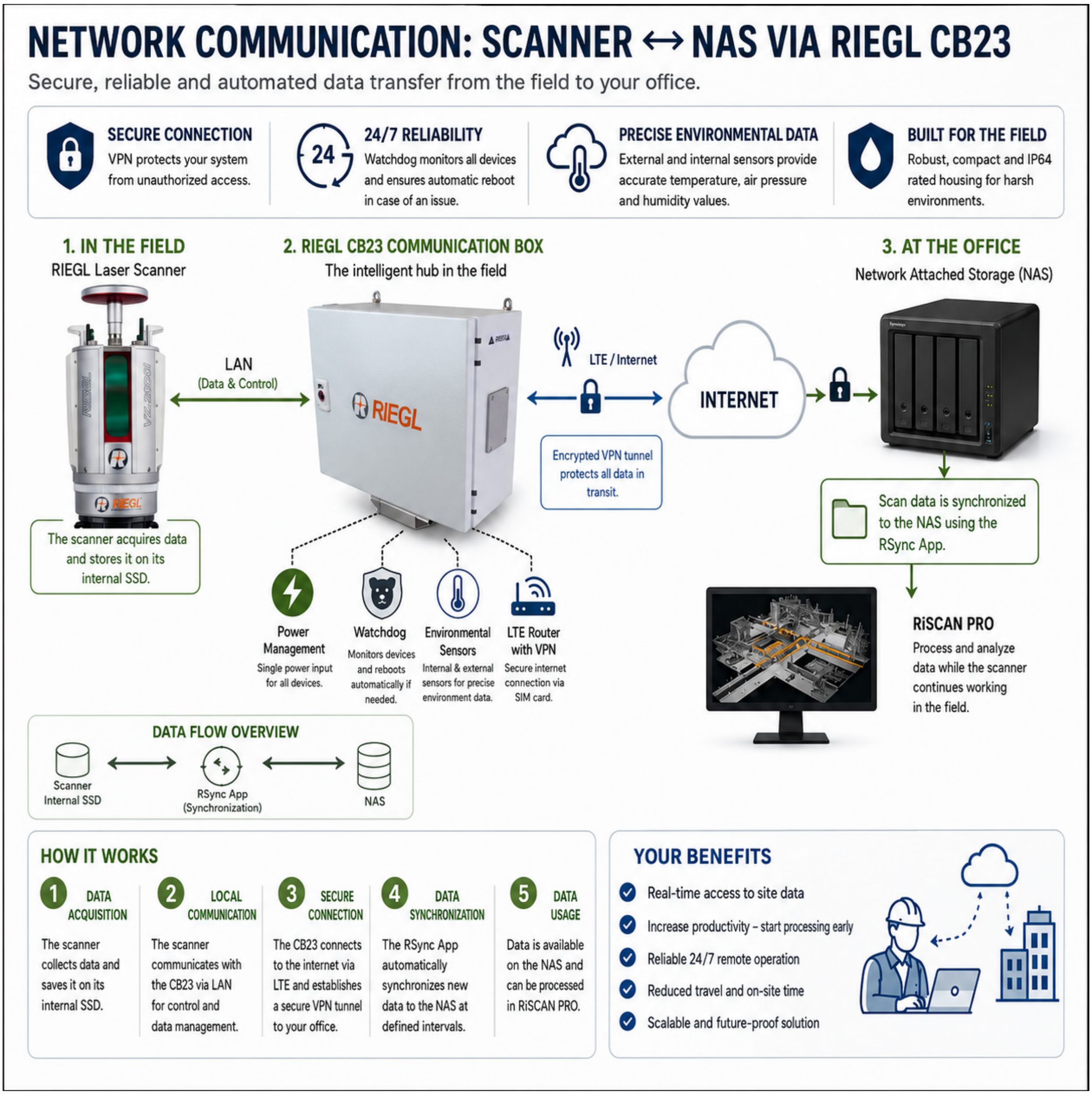
REFERENCE 22.06.2021 09:15:28
COMPARE 30.06.2021 00:15:31
Every 1 scan

[Manual – Monitor+ App](#)

Appendix 9 – Mounting a NAS and RSYNC App

Data synchronization from a *RIEGL* scanner to a Network Attached Storage (NAS) enables efficient remote data transfer from the field to the office. The NAS is first mounted on the scanner via the network settings, using the appropriate host/IP address, protocol, shared path, and user credentials. Once mounted, the NAS becomes available as a target storage medium.

For efficient operation, scan data should remain on the scanner's internal SSD during acquisition. The RSYNC App then automatically synchronizes the active project to the NAS at a defined time interval. This background process transfers newly acquired data without interrupting ongoing scanning activities. With a reliable internet connection, data can be made available almost in real time, allowing office-based teams to start processing or reviewing the project while the scanner is still operating in the field.


NETWORK COMMUNICATION: SCANNER ↔ NAS VIA RIEGL CB23

Secure, reliable and automated data transfer from the field to your office.

SECURE CONNECTION VPN protects your system from unauthorized access.

24/7 RELIABILITY Watchdog monitors all devices and ensures automatic reboot in case of an issue.

PRECISE ENVIRONMENTAL DATA External and internal sensors provide accurate temperature, air pressure and humidity values.

BUILT FOR THE FIELD Robust, compact and IP64 rated housing for harsh environments.

1. IN THE FIELD
RIEGL Laser Scanner

The scanner acquires data and stores it on its internal SSD.

2. RIEGL CB23 COMMUNICATION BOX
The intelligent hub in the field

Power Management Single power input for all devices.

Watchdog Monitors devices and reboots automatically if needed.

Environmental Sensors Internal & external sensors for precise environment data.

LTE Router with VPN Secure internet connection via SIM card.

Encrypted VPN tunnel protects all data in transit.

3. AT THE OFFICE
Network Attached Storage (NAS)

Scan data is synchronized to the NAS using the RSync App.

RiSCAN PRO Process and analyze data while the scanner continues working in the field.

DATA FLOW OVERVIEW

HOW IT WORKS

1. **DATA ACQUISITION** The scanner collects data and saves it on its internal SSD.
2. **LOCAL COMMUNICATION** The scanner communicates with the CB23 via LAN for control and data management.
3. **SECURE CONNECTION** The CB23 connects to the internet via LTE and establishes a secure VPN tunnel to your office.
4. **DATA SYNCHRONIZATION** The RSync App automatically synchronizes new data to the NAS at defined intervals.
5. **DATA USAGE** Data is available on the NAS and can be processed in RiSCAN PRO.

YOUR BENEFITS

- ✓ Real-time access to site data
- ✓ Increase productivity – start processing early
- ✓ Reliable 24/7 remote operation
- ✓ Reduced travel and on-site time
- ✓ Scalable and future-proof solution