WHITE PAPER

RIEGL V-Line Scanners for Permanent Monitoring Applications and integration capabilities into customers risk management

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Introduction

Analysis of mass movements and of geomorphic processes in general are a key subject in the prevention of natural hazards and protection of infrastructure (Bremer et al., 2019). Such events are induced by various environmental processes as drivers while their occurrence is causally linked to climate change, therefore posing an increasing risk in terms of magnitude and frequency (Huggel et al., 2012). In the context of climate change and the expansion of areas of urban settlement, e.g. in Alpine regions, the demand for high-quality, i.e. spatially and temporally detailed, datasets as well as the integration in risk management as an early warning system is increasing.

Basic procedures for measuring geometric changes have been established for decades without being a special challenge of laser scanning. A monitoring program must be individually adapted to the observed object to significantly detect geometric changes. It must be taken into account that spatially discretization of the object must be done according to the expected displacements. Additionally, the temporal discretization must be considered. Thus, no significant displacements may occur during a measurement epoch and no movements may remain unobserved due to the interval between two measurements. Both in the past and nowadays, manual, campaign-by-campaign measurements are preferred for certain monitoring tasks. However, this is a disadvantage if I do not know exactly which specific processes I am looking for.

Monitoring high-mountain areas is difficult and dangerous. Remote sensing techniques are preferable to achieve adequate spatial and temporal coverage (Hermle et al., 2022). *RIEGL* Terrestrial Laser Scanners have been used for more than 20 years for topographic surveying and monitoring purposes. The technical advancement of *RIEGL* laser scanners towards communication-capable, programmable multi-sensor systems, a compact and robust design as well as economically attractive systems allow permanent laser scanning (PLS) installations in areas of interest and their integration into near real time early warning systems. In order to set up a monitoring system, no prior knowledge of the expected movement characteristics is required.

In addition to the technical requirements for the sensor technology itself, the conditions for data integration, data storage and finally visualization must be met within a holistic risk management system. In this context, the laser scanner complements existing sensor technology in a targeted manner and is not to be understood as a substitute.

This white paper presents the technology of *RIEGL*, its technical possibilities as well as its application in the context of permanent monitoring. In particular, the ability for user-specific system integration by means of open system architecture based on software is shown. DMT GmbH & Co. KG has integrated the scanner into its DMT SAFEGUARD monitoring system based on these capabilities and can offer tailored solutions to its customers in the mining and infrastructure sectors.

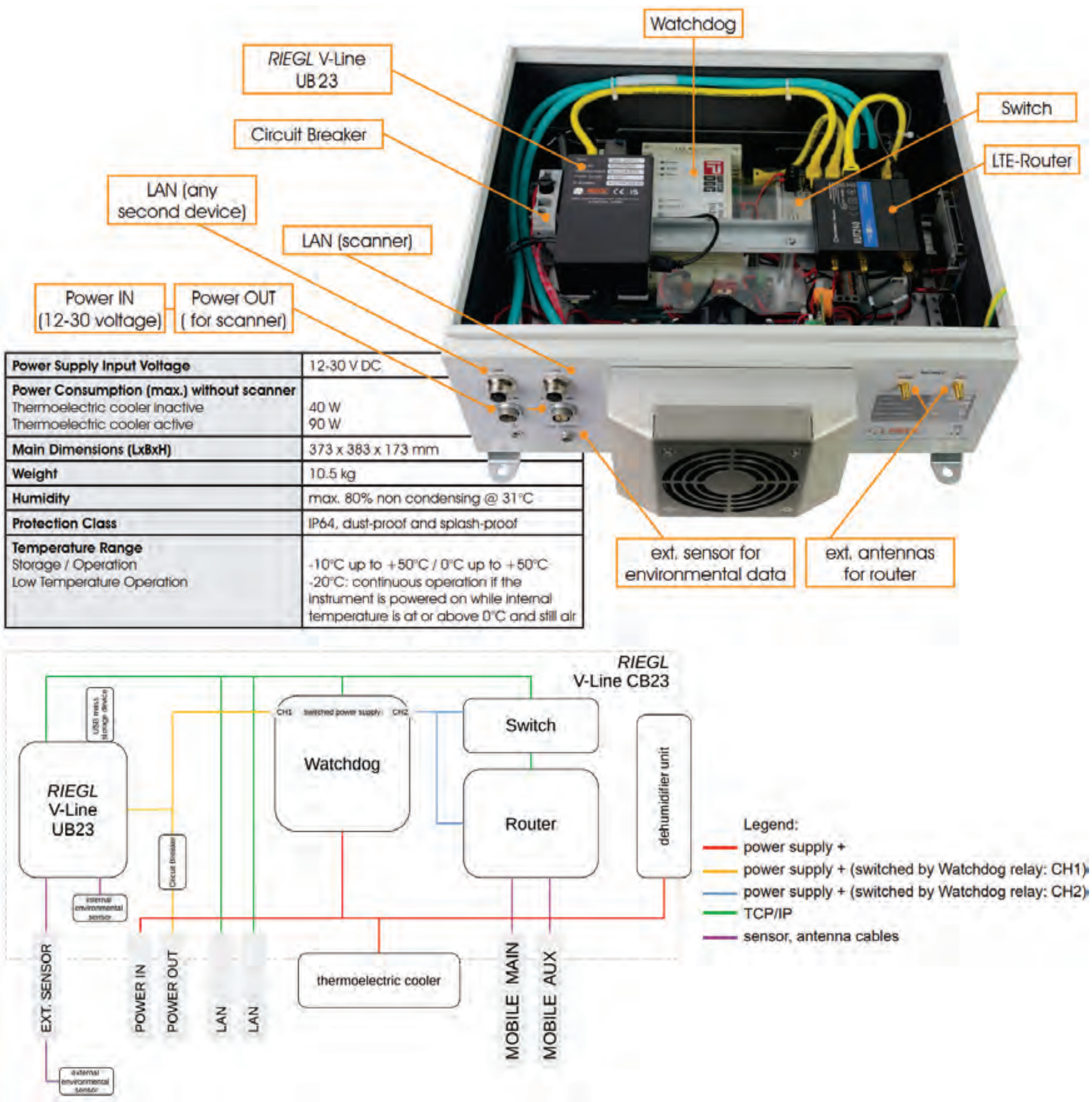
RIEGL V-Line Scanners

2008 *RIEGL* introduced the VZ-400 - The first *RIEGL* V-Line scanner enabling online waveform processing. This technology allows multiple target capability, calibrated amplitude and calibrated reflectance readings. Furthermore, it guarantees high accurate range readings even at long ranges and in bad environmental conditions (rain, snow, fog, dust). In the following years a number of new *RIEGL* terrestrial laser scanners with extended range measurement capabilities were introduced. The VZ-6000 offers a maximum range of 6000 m even on snow and ice. Multiple Time Around (MTA) processing is a key technology to measure long ranges in combination with high measurement rates. In 2016 the *RIEGL* VZ-i

Series was introduced. The fully new designed hardware including a data processing board allows multiple processing tasks already being executed on board. Furthermore, an open LINUX operating system allows customizing the scanner for special purposes by running apps in C++ and python scripts on the scanner. This enables programming of specialized apps delivering just in time results on the scanner for special application. These features make the hardware practicable for use within a monitoring system. Reliability is supported by the compact and robust design in a dustproof and splash-proof housing (IP64).

24/7 Remote Scanner Operation

RIEGL scanners are well known for stable operation even under harsh conditions. Nevertheless, it might happen that some malfunction occurs and the scanner is not responding or operating anymore. In such a case it might happen that the graphical user interface (GUI) is not responding anymore. From remote there is no way to solve this problem. The power supply must be cut and re-connected, which forces a reboot of the scanner. But how to realize that if the scanner is operating at a remote place, where nobody is available to cut the power? For such an environment *RIEGL* offers the V-Line CB23 communication box, which guarantees 24/7 operation of the whole system (Fig. 1).



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)	373 x 383 x 173 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

Figure 1. V-Line CB23 for *RIEGL* V-Line Scanner

This box comprises a standard router with standard Sim-card to enable internet access. Remote communication is realized via a VPN connection, which guarantees protection against unauthorized access. Fig. 2 shows the software MobaXterm (https://mobaxterm.mobatek.net/), which can handle multiple communications sessions like FTP, SSH, VNC, etc. We use a VNC-viewer to establish communication with the graphical user interface of the scanner. SSH is used to communicate with the scanner via its Linux shell. Also access to the scanner's integrated FTP-server is possible. Of course, the user can run other software solution like putty for SSH communication, any FTP client software, and the *RIEGL* VZ-i series App as VNC viewer.

RIEGL V-Line CB23 includes also an external sensor for measuring environmental data (temperature, pressure, humidity). This data can be used on the connected scanner to apply a high accurate atmospheric correction on the scan data. Finally, the *RIEGL* V-Line CB23 includes a microcomputer, which runs similar software as the post-processing board of the VZ-i series scanners. This allows also to connect older VZ-series scanners with the CB23. In this case the already mentioned apps are running on this microcomputer, while the connected scanner just delivers the raw scan-data.

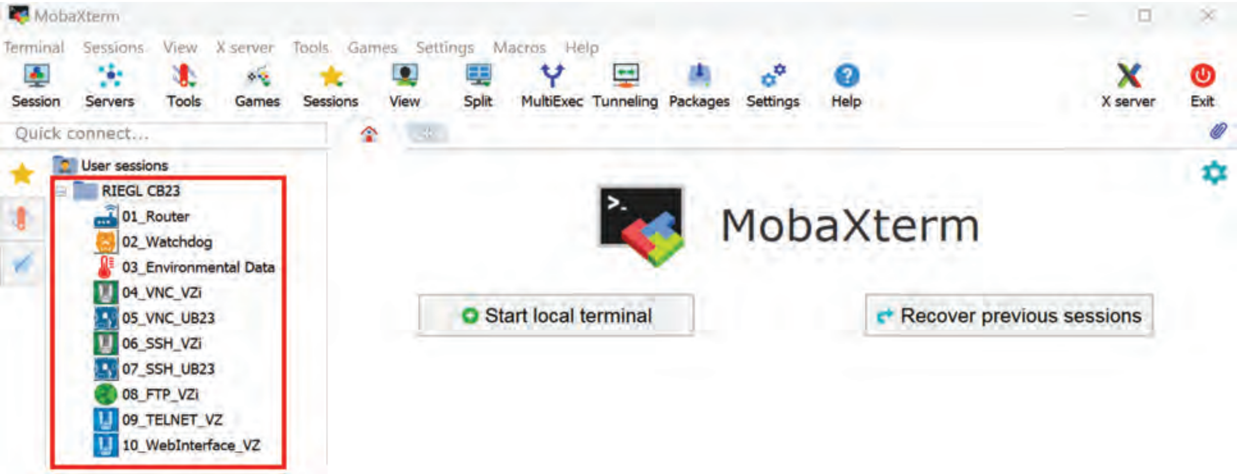


Figure 2. Software MobaXterm to establish multiple communication ports with the *RIEGL* V-Line CB23

A hardware "watchdog" is installed inside the communication-box. This hardware component checks all other connected hardware devices for proper operation. It sends pings on a defined schedule to check the vitality of the connected devices. In case of no response from the pinged device the watchdog activates a power-relay to enforce a hard reboot of the not responding component. An email notification will be sent to a configured e-mail address. Besides the connected scanner also the router itself is observed by the watchdog. Even a manual reboot of the whole system from remote is possible by using the watchdog's web-interface. If the scanner is operated in combination with the *RIEGL* communication box, we can guarantee a stable 24/7 remote scanner operation. The

New: Corner Cube Prism detection

New scanners as well as existing scanners with current firmware offer the possibility to detect corner cube glass prisms from a minimum distance of 200 m to the scanner. In a second step, the detected prisms are scanned in high resolution and the prism center is calculated.

This new functionality opens up a wide range of applications and benefits. On the one hand, these targets are easy to install in the object space due to their compact design and are less sensitive to physical influences than conventional targets. Furthermore, due to their radiometric interaction with the laser scanner, corner cube prisms are not required to be proportionally sized to the measurement distance. Besides these properties it is essential that by means of these prisms a combination with other sensors within a monitoring project is possible without any restrictions and thus a homogeneous georeferencing of all sensors can be achieved. Beyond the obvious connection of Laser Scanner and Total Station, GNSS as well as satellite InSAR or GBInSAR can be integrated via modified target signs, without intending to complete this enumeration.

In the Appendix you can find detailed description of the functionality and a precise and accuracy evaluation.

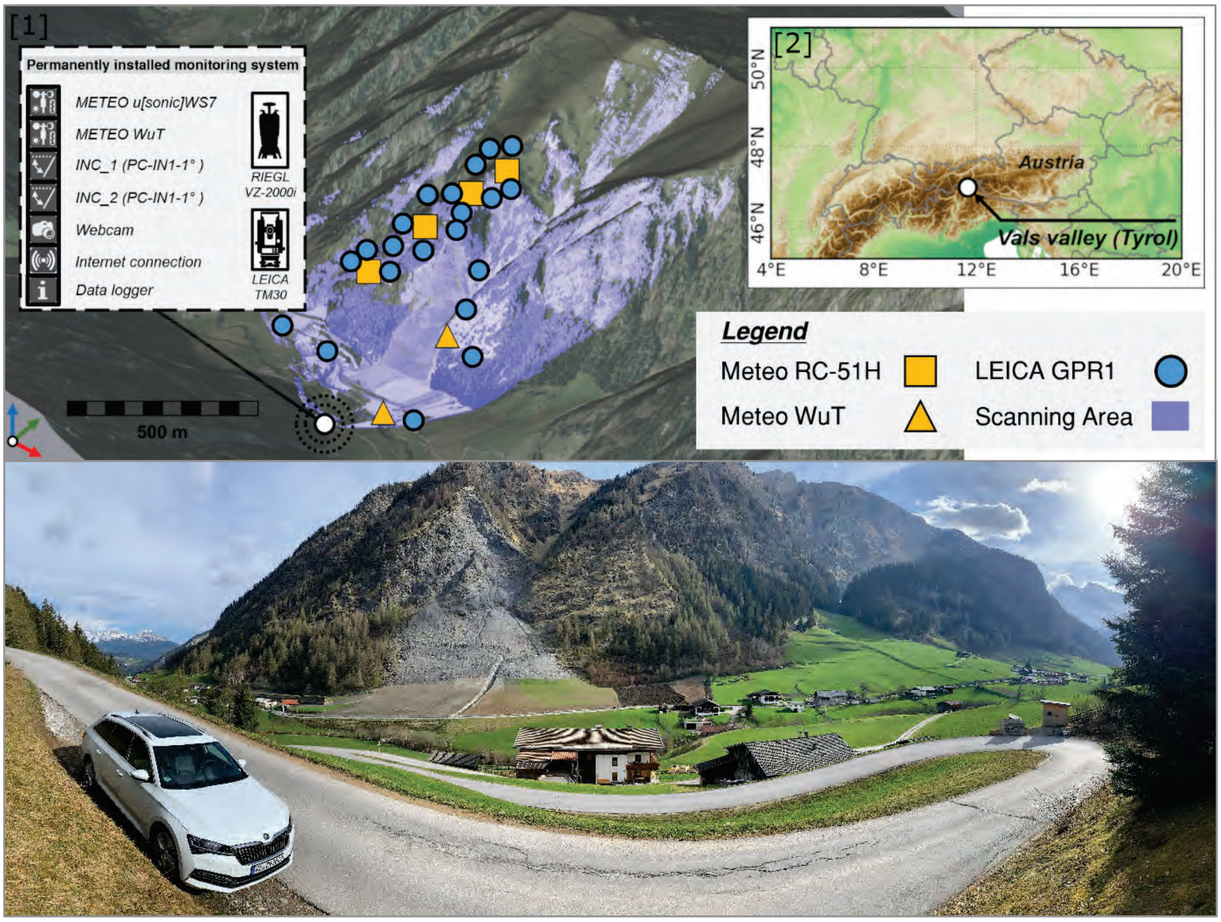


Figure 3. Three-dimensional overview of the test site in the Vals Valley including applied sensor technology and overview of the geographical situation of the Vals Valley. (Data Source: Land Tirol - data.tirol.gv.at [1] and http://ows.mundialis.de/

Case study: Site description

Based on the latest developments at *RIEGL*, we demonstrate in this paper the comprehensive possibilities to integrate a laser scanner into your risk management by presenting an example project in Vals / Austria (Fig. 3). Our study area is the Vals Valley in Tyrol (Austria). A rockfall occurred in this area on 24 December 2017. Though causing neither human casualties nor significant damage to buildings, a road located directly below the rockfall slope was covered with 8 m of debris and a total volume of 116,000 m^3 of rock was relocated (Hartl, 2019). The local authorities set up a geodetic monitoring system, consisting of a total station (Model: LEICA TM30) with 21 corresponding prisms (Model: LEICA GPR1) and geotechnical sensors (e.g., extensometers) distributed on the mountain slope.

Point cloud data was recorded during several campaigns since 2020 using the *RIEGL* VZ-2000i laser scanner permanently installed on a survey pillar in a shelter (to protect the scanner from atmospheric influences like rain, sun, wind, etc.) on the opposite slope about 800 m from the area affected by the rockfall. The rockfall area

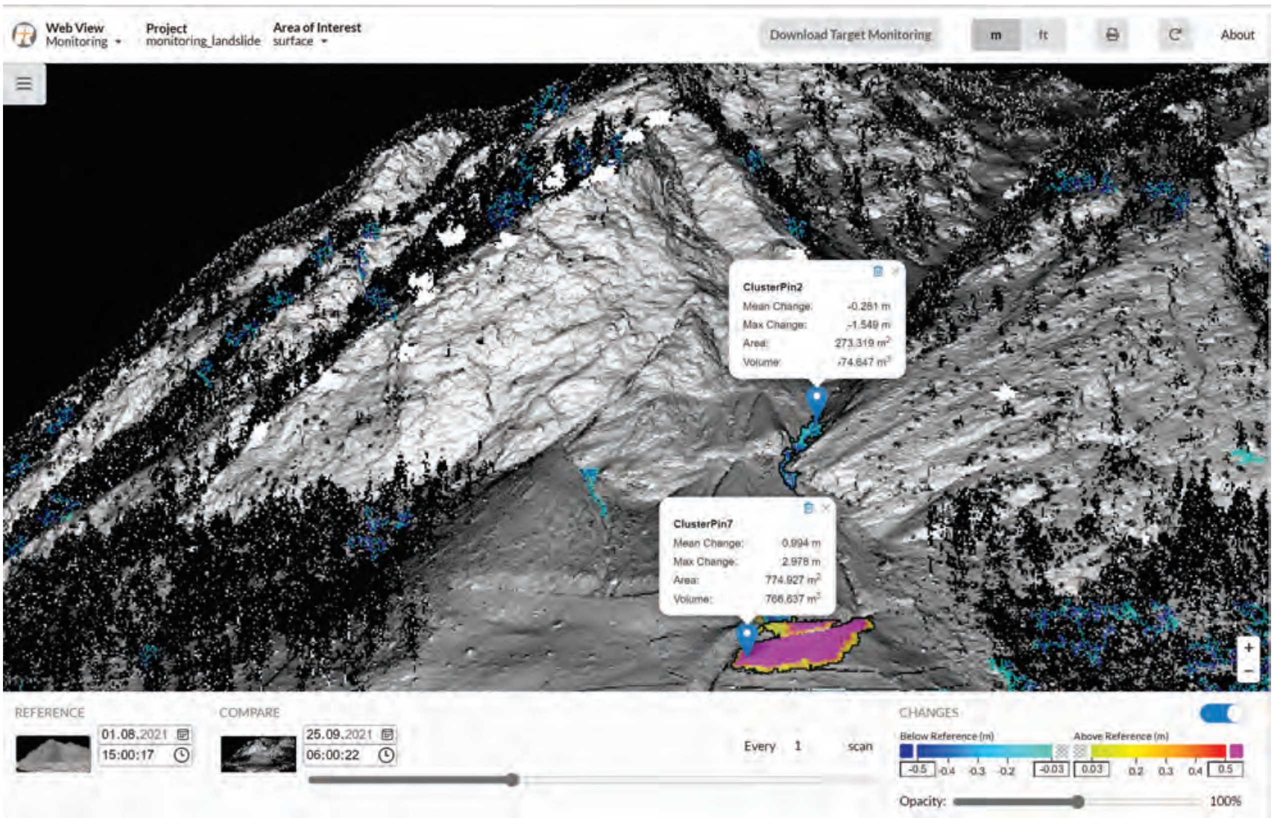


Figure 4. Web Viewer Monitor+App

itself was scanned every three hours with an angular resolution of 0.015°, resulting in a point spacing of approx. 14 cm in 500 m range. In the time between consecutive fine-scans of 21 corner cube prisms were performed every 20 minutes.

This dataset is designed to demonstrate the capability of using long-range terrestrial laser scanners in a remotely controlled, web-based monitoring system.

Case study: *RIEGL* Monitoring Workflow

Monitor+ App

RIEGL developed a suite of monitoring apps for the VZ-i series scanners to enable automatic data acquisition and processing followed by a remote visualization of the processing results by an integrated web-server. A detailed description of the web-viewer (Fig.4) functionality follows in the next chapter of this paper. The monitoring apps are a bundle of apps – the Monitor+ App, the Monitoring App, the DesignCompare App, and the SlopeAngle App. The Monitoring App compares the actual scan to a defined reference scan and visualizes the differences via a web-viewer, which runs on all standard web browsers. The DesignCompare App compares the actual scan not to a reference scan, but to a given design model. Finally, the SlopeAngle App calculates local slope angles and visualizes the slope angles color encoded. These three apps are already almost 2 years on the market. We got a lot of customer feedback and developed based on this feedback the brand-new Monitor+ App. The Monitor+ App is a solution not only for permanent monitoring, but also for periodic and sporadic monitoring. It allows now also to interrupt the monitoring schedule, remove the scanner, and use the scanner temporary for other surveying purposes.

Once the scanner is returned and mounted on almost the same position the monitoring can be continued. The app automatically aligns the new position to the data acquired earlier, so that correct change detection is guaranteed. Furthermore, the new Monitor+ App also supports automatic prism monitoring on a defined schedule. This means that the Monitor+ App can do the work of traditional prism monitoring, how it is already realized by robotic total stations, but furthermore offers all the advantages of complete surface monitoring.

In our case study the Monitor+ App is used in order to detect potentially critical topographic changes. In the following we highlight in detail how the Monitor+ App works. Any app installed on the scanner supports the user with an integrated graphical user interface (GUI), which guides the user through the different steps. Due to the high flexibility and therefore quite complex configuration of the Monitor+ App the user is supported by a configuration wizard within our standard scan data processing software RiSCANPRO. This wizard guides through defining area of interest, scan resolution, selecting prisms/targets for monitoring, threshold values settings, alignment settings, and scheduling. The resulting configurations and schedules are stored in json file format. These two files are copied on to the scanner and activated via the GUI of the Monitor+ App (Fig. 5). A more detailed description of the Monitor+ App configuration wizard within RiSCANPRO is available in the Appendix of this paper. Once the

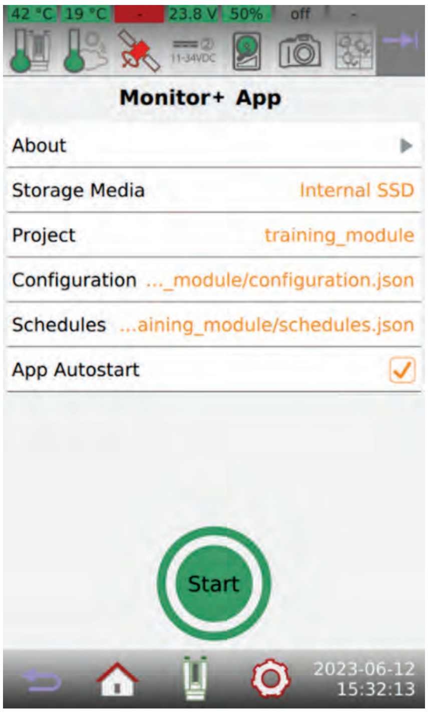


Figure 5. GUI Interface Monitor+ App

"Start" button is activated the whole data acquisition runs autonomously following the given configuration and schedules. On pressing the "Stop" button the data acquisition is interrupted. Now the scanner can be removed and used for other purposes. Later the scanner can be remounted and data acquisition will be restarted. In this case first a position alignment following the rules defined by the Monitor+ configuration wizard of RiSCANPRO and stored within the configuration file is performed, thereafter monitoring data acquisition is proceeded.

With each data acquisition epoch, the Monitor+ App analyses the point cloud in the scanner's polar coordinate system and converts the point cloud into an easy-to-handle, compressed 2D representation for subsequent analysis of differences between two distinct data sets. As over long periods of time the external orientation of the laser scanner is not absolutely constant, the App also determines with each data acquisition epoch any small changes in the external orientation and/or position with respect to the first data set. All 3D lidar points are rasterized on a regular grid in azimuth angle and polar angle. All data points within a raster cell are statistically analyzed to generate a 2D image with range and surface orientation information. For the visualization of changes two of these 2D data sets are compared against each other. The comparison is done "on-the-fly" within the web viewer.

In the Appendix the calculation steps incl. formulas are described in detail.

Results of Monitor+ App

As already mentioned, installed corner cube prisms were monitored besides monitoring the whole landslide. The coordinates and ranges of the acquired prisms/targets can be downloaded as csv-file via the button "Download Target Monitoring" on the web-viewer (Fig. 4) and feed in any automatic prism monitoring system for visualizing the collected data on time diagrams. Besides that, the SAFEGUARD APP from DMT offers web-based time diagram visualization of the prism/target information (see next chapters). The DMT SAFEGUARD APP can run parallel with the Monitor+ App on the scanner.

Once the user selected the area of interest on the web-viewer the acquired data from this region is visualized either as greyscale reflectance image or as shaded relief as in Fig. 4. On the bottom of the web viewer any of the acquired epochs can be defined as reference. Using the slide-bar the user can navigate through all data epochs and the differences to the given reference epoch are visualized. On the lower right side of the web viewer the default threshold values and color-tables defined by the configuration of the Monitor+ App are shown. All these settings can be adjusted within the web-viewer. By moving the cursor over highlighted pixels, the range value and change value of the actual epoch to the given reference epoch are shown. The user can also set a pin for permanently highlighting these values while sliding through the data epochs. By clicking on the button on the upper left corner of the data visualization the user gets access to all further settings of the web-viewer (Fig. 6). “Appearance” defines how the data is visualized, either as greyscale reflectance image or as shaded relief. “Cluster Analysis” is highlighting clusters of a defined minimum number of neighboring pixels. If neighboring pixels showing a range value difference more than the depth tolerance value, they are not considered to belong to the same cluster. Pixels not meeting the given criteria are suppressed. Moving the cursor over clusters or setting pins on clusters is showing further change information as in Fig 4. “Selection Analysis” allows defining a polygon of interest on the image. The mass balance within this selection is shown. “Readout and Pin Information” controls what kind of data is shown while moving the cursor over the image or setting a pin. “Import/Export” allows exporting all settings of the actual web-viewer visualization. When starting the web-viewer again, it opens with all default settings, because no user is allowed to change settings to avoid conflicts between different users. By importing the prior exported settings, the user gets his customized settings back. “Statistics” shows statistical information about the quality of position alignment and epoch adjustment. Position alignment is performed on restarting the monitoring by pressing the “Start” button, while epoch adjustment is performed on every scan data acquisition epoch. This guarantees that minimal movements/changes of the scanner mounting are not influencing the quality of change detection.

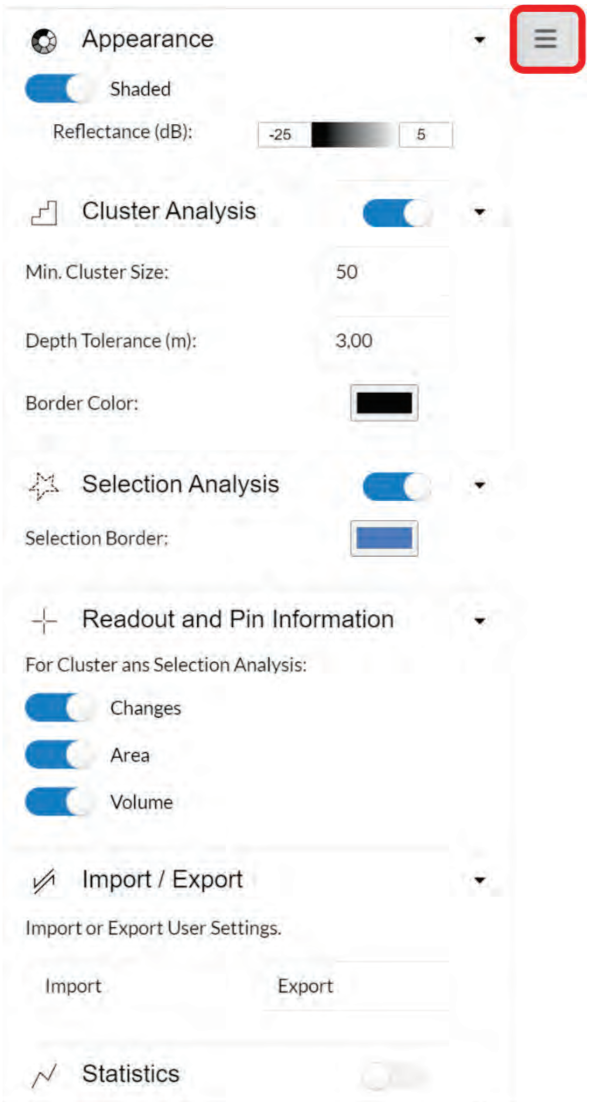


Figure 6. Monitor+ Web Viewer Settings

Data Synchronization

As described in the chapters before the whole system is designed to work 24/7 even in remote and harsh environments. Off course stable power supply for operation of scanner and communication box has to be guaranteed. The micro sim-card inside the router of the communication box enables remote operation of the whole system.

The data of the Monitor+ App is stored on the internal SSD of the scanner, which provides almost one Terabyte of disk space. One day (24h) data acquisition results in this setup of Vals (defined by scan pattern, number of prisms, schedules for data acquisition) in approx. 7 GB of raw data. The derived results from the raw data (data visualized on the web viewer of the Monitor+ App and coordinate-lists in csv format from the prism monitoring) consists only of 60 MB a day, which is roughly 1 percent of the raw data. As already mentioned earlier the scanner itself runs a web-server, which is utilized by the Monitor+ App to publish the results. Nevertheless, we recommend to synchronize at least the final result data onto an external diskspace. This avoids lot of data traffic in case many different groups of people view the data of the Monitor+ App on their computers. Via the graphical user interface (GUI) of the scanner an external network attached storage (NAS) can be mounted (Fig. 7).

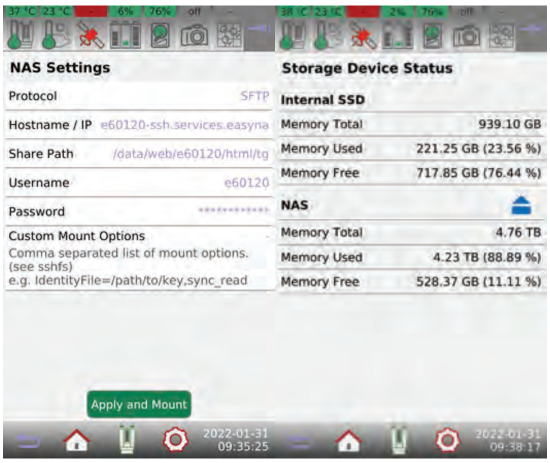


Figure 7. Mounting a NAS for data synchronization

Ideally, the NAS can be accessed from the internet and runs a web server for publishing the data. Depending on the available band-width for internet connection it has to be decided, if the full raw data or only the one percent of the raw-data, the final results, are synchronized. The Rsync App on the scanner allows data synchronization of an active project onto a mounted NAS (Fig. 8). By making use of the "Rsync Options" additional parameters for the Rsync command can be defined. The screenshot (Fig.8) shows that all directories containing the scan raw data are excluded from the synchronization.

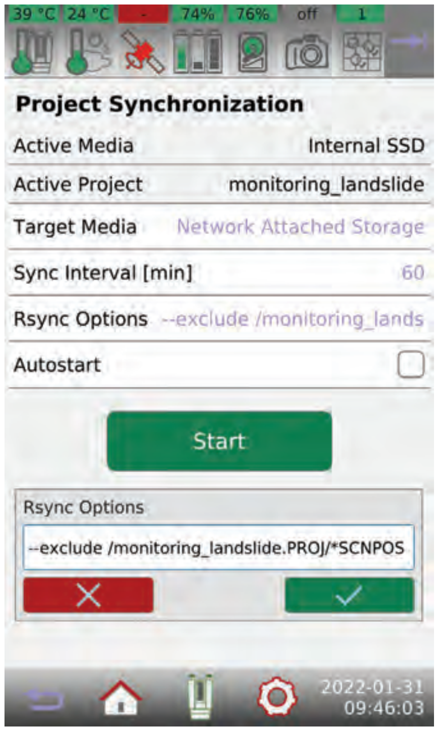


Figure 8. Rsync App for data synchronization

Case study: Integration into customers risk management

At this point, the *RIEGL* Laser Scanner, the communication box, and the software options for individual integration are presented. Any user has the possibility to perform own integrations based on these developments. In the second part of this white paper, we present the integration of scan data into external software. The integration offers the advantage to manage the scanning data in a central platform together with the data of other sensors and to generate information from the data. DMT GROUP's web-based monitoring platform DMT SAFEGUARD is used as an example to demonstrate the integration.

DMT SAFEGUARD

DMT SAFEGUARD is a web-based data management and geoinformation system (IoT platform) for all types of monitoring tasks in the construction industry, mining and for infrastructure projects, with which geotechnical monitoring data can be easily collected in a common database, displayed online, analyzed and archived. As an integral part of your professional risk management, DMT SAFEGUARD enables fast and informed decisions for any phase within your projects.

DMT SAFEGUARD enables the integration of data and sensors independent of the type, format, manufacturer and source. Through automated data evaluation, alarm messages e.g., in case of detected ground movement, can be generated and submitted the user.

SAFEGUARD APP

The focus of the DMT SAFEGUARD APP is the integration of area-based sensor technology and is intended to provide all stakeholders with a range of advanced monitoring, measurement and analysis tools, for example, to determine the impact of a rockfall in terms of ground and slope movements and to support them with important information on the condition of the ground surface.

While the web-based DMT SAFEGUARD application collects all relevant monitoring data on a central server, the SAFEGUARD APP is available on the scanner itself (Fig: 9) and works with local data stored in the scanner's file system. The SAFEGAURD APP is realized as a web service and can be operated as an application within any browser connected to the scanner.

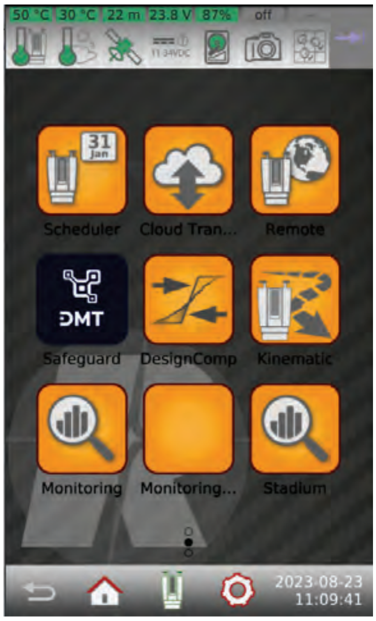


Figure 9. The GUI of the scanner with the installed SAFEGUARD APP

In this section we demonstrate in detail the data flow to SAFEGUARD APP. As described above, the scanner is set up and installed in the shelter on a pillar in the Vals Valley in Austria. The *RIEGL* V-Line CB23 is connected to the scanner via LAN. The box provides an appropriate power supply and internet connectivity - in the Vals Valley, this is based on a LTE connection. The scanner can be used worldwide and is available to many different users within a project.

Input data for the SAFEGUARD APP are collected either by means of the *RIEGL* Monitoring App and the Scheduler App or by means of the new *RIEGL* Monitor+ App. The SAFEGUARD APP recognizes automatically according to which scheme you have created your scan project. Projects that are managed by means of the *RIEGL* Monitor+ app are given a corresponding prefix in the project list (Fig. 10). Otherwise, there is no remark. The SAFEGUARD APP can be operated in parallel with the *RIEGL* monitoring apps on the scanner. Thus, time series can be up-to-date with the scan acquisition in real time. On the other hand, already acquired projects can be selected and you can analyze historical measurement data with the SAFEGUARD APP.

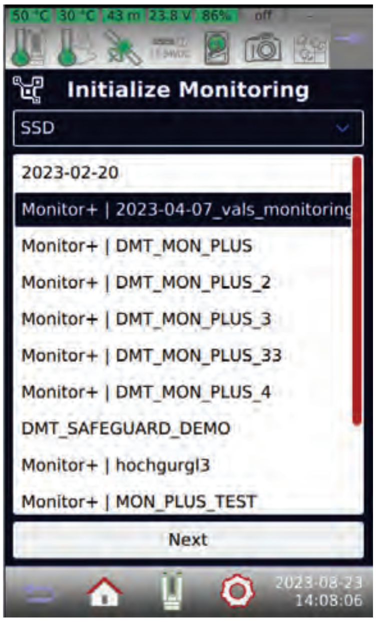


Figure 10. Step 1: Selecting a monitoring project

After the project has been selected in the first dialogue screen of the APP (Fig. 10), the data to be used for visualization via SAFEGUARD APP can be selected. The options for data selection depend on the parameterization of the workflow via RiSCANPRO when using the Monitor+ App, for example. On the one hand, time series of the control reflectors (Fig. 11) which are used for project alignment and epoch adjustment can be visualized, and on the other hand, the time series of the monitoring reflectors can be presented (Fig. 12).

An additional feature, which is offered exclusively in the SAFEGUARD APP, can be initialized in the next dialogue screen. Using the SAFEGUARD APP, clusters, selections, or pins can be illustrated according to their temporal evolution (Fig. 13 & 14). For this purpose, corresponding selections and pins must be chosen via the web view of the Monitoring+ App and exported as a JSON file. This file must be copied onto the scanner to the folder indicated in the SAFEGUARD APP. The requested clusters, selections, or pins can then be added (Fig. 13), so that selected areas can be monitored directly in the 3D data without the need for artificial markers in the measured area.

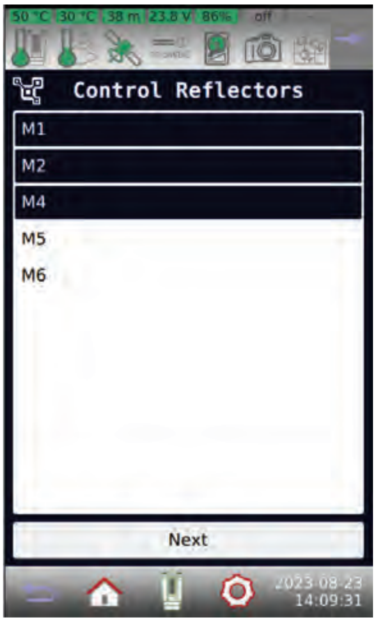


Figure 11. Step 2: Selecting Control Reflectors

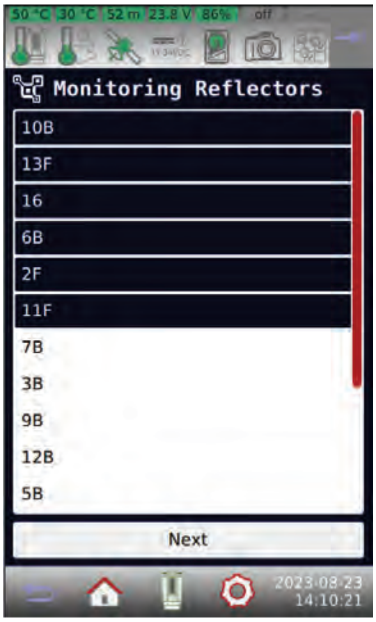


Figure 12. Step 3: Selecting Monitoring Reflectors

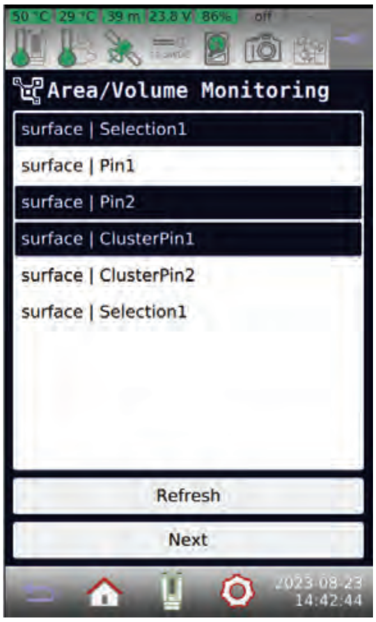


Figure 13. Step 4: Selecting clusters, selections or pins

Figure 14. Step 5: Selecting threshold values

Finally, you can choose threshold values in order to visualize the time series of the reflector markers (Fig. 14). The app distinguishes between 2 levels. One is a warning value and the other is an alarm value. It is important that the user selects these values independently, based on their own expertise. Moreover, the values are only visually displayed according to their threshold color and no automatic action is carried out when a threshold is exceeded. In addition to the warning values, a value for the quality of the reflector detection can also be selected, so that measurements with poor quality, e.g., due to rain or snowfall, can be excluded from the evaluation.

Any device that has a browser and is integrated in the same network as the scanner has access to the web server with the monitoring data.

Accessing the URL of the web server initially opens the welcome screen of the SAFEGUARD APP with general information (Fig. 15). The various tabs provide access to the *RIEGL* web view and the generated time series (Fig. 16).

In addition, with georeferenced projects, the position of the scanner and the selected reflectors are plotted on a map (Fig. 17).

DMT SAFEGUARD allows decision makers to quickly obtain relevant information. Multiple users can work simultaneously in the platform, enabling collaborative teamwork at any time and in real time.

The case study is available as a demo:

https://safeguard.dmt.de/riegl

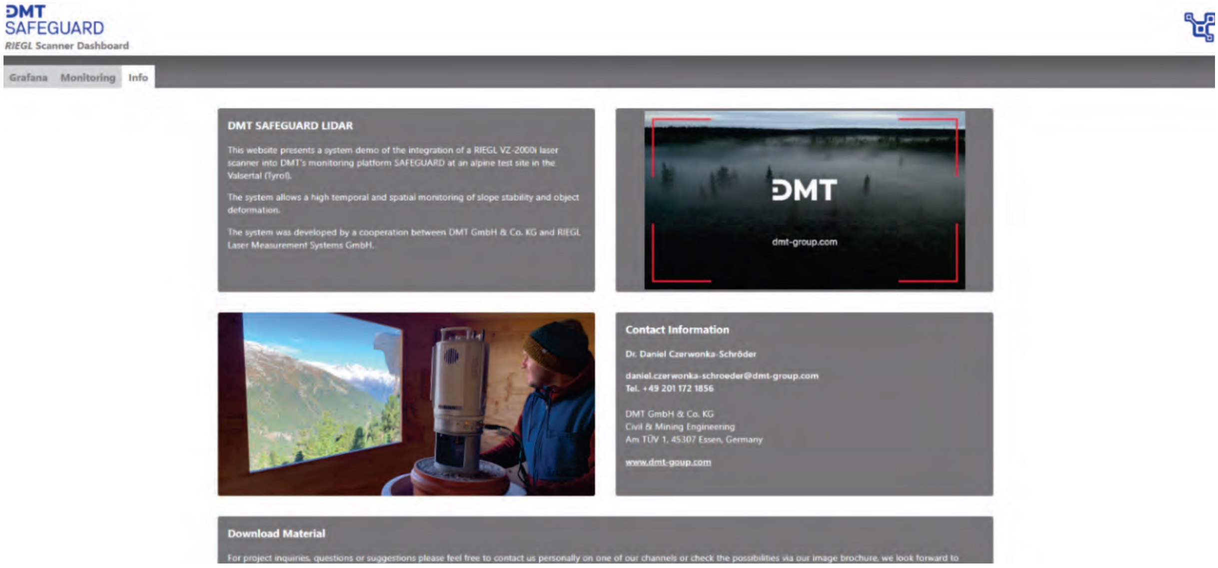


Figure 15. Welcome screen of the SAFEGUARD APP

Figure 16. Time Series of selected reflectors as well as clusters, selections or pins

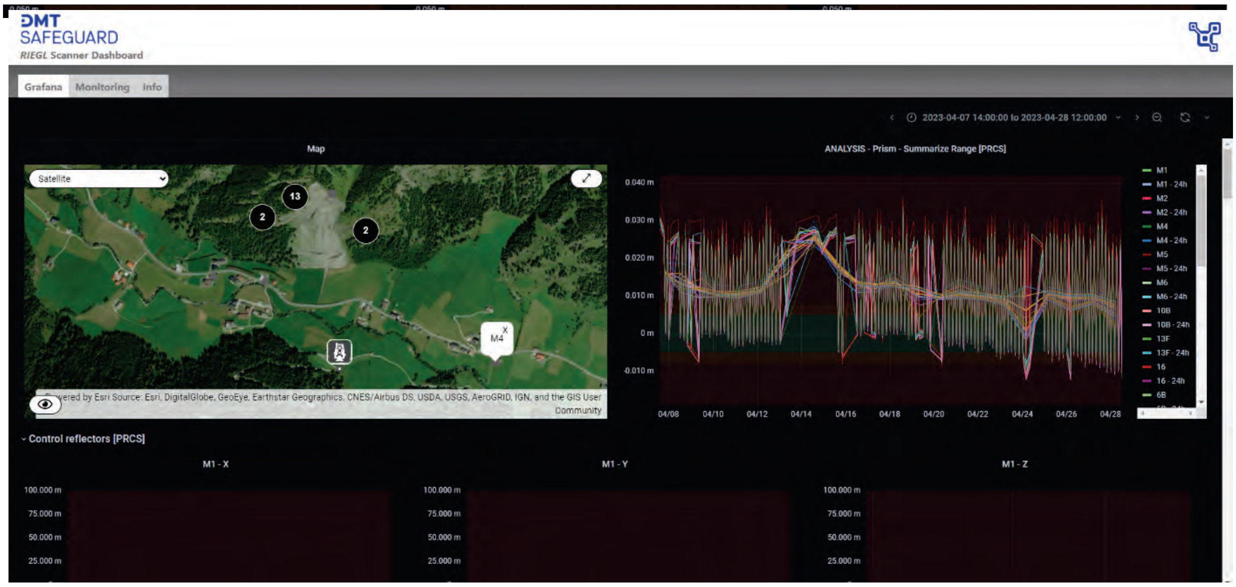


Figure 17. Map view of selected reflectors as well as clusters, selections or pins

Conclusion

With DMT SAFEGUARD a precise integration of *RIEGL* laser scanners into a web-based platform is available. In addition to the functionalities presented here, the system can be expanded as desired by DMT experts. The individual customization options allow additional sensors to be integrated directly on site or external data sources to be integrated as well. GIS functionalities allow the integration of maps in order to display the most important data.

The open architecture of the *RIEGL* VZ-i Series scanners allows customizing the scanner for complex data acquisition and processing tasks by means of Python scripts and Python-based Apps. *RIEGL*'s proven online-waveform-processing technology ensures high quality data even under harsh environmental conditions. 24/7 system operation and fully remote system operation has been proven. Laser scan data is processed by integrated apps in real time on the scanner and final results are visualized via a web-viewer tool running on all standard web browsers. Based on the example of DMT SAFEGUARD, we have shown that the scanner can be integrated in various applications and demonstrated a high degree of flexibility.

References

Bremer, M., Zieher, T., Pfeiffer, J., Petrini-Monteferri, F., & Wichmann, V. (2019). Monitoring der Großhangbewegung Reissenschuh (Schmirntal, Tirol) mit TLS und UAV-basiertem Laserscanning. Hanke, K.; Weinold, 321-33.

Huggel, C., Clague, J. J., & Korup, O. (2012). Is climate change responsible for changing landslide activity in high mountains?. Earth Surface Processes and Landforms, 37(1), 77-91.

Hermle, D., Gaeta, M., Krautblatter, M., Mazzanti, P., & Keuschnig, M. (2022). Performance Testing of Optical Flow Time Series Analyses Based on a Fast, High-Alpine Landslide. Remote Sensing, 14(3), 455.

DVW (2014). Merkblatt 8-2014: Vermessungspfeiler. https://dvw.de/component/cck/?task=download&file=anhang&id=1722 (01/04/2022)

APPENDIX – *Detailed information on…*

… Prism detection

Based on the reflectivity of the measurements on a prism, two thresholds are calculated - "Cut low" and "Cut high". All points with reflectivity above "Cut high" are part of the prism core. All the other measurements points with reflectivity between "Cut low" and "Cut high" belong to the environment of the prism. For the calculation of the three-dimensional center of the prism, both the core and the environment are used. For the core itself, the center of gravity is calculated. Through the environment, in turn, a plane is estimated. The calculated center of gravity is projected onto the plane. Thus, the core is used to determine the position (theta, phi) and the environment is used to estimate the distance (range).

The precision and accuracy of prism detection is specified in 2 scenarios for distance measurements up to 1200 m - this distance refers to the test scenario. Prism detection works across the complete range of the *RIEGL* laser scanner. The precision was determined by measurements over 4 weeks on 21 glass prisms under real conditions in the Vals valley. The parallel use of a total station allows the measurement systems to be compared under similar conditions. The precision values are presented for the single measurement (transparent color) and a daily average (opaque color).

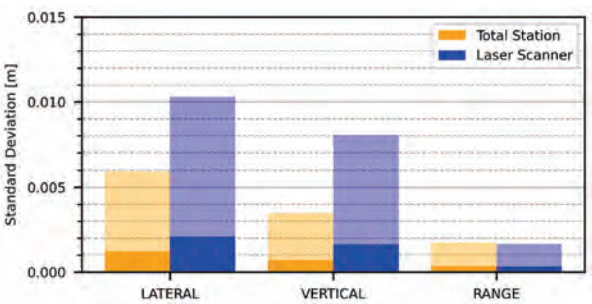


Figure A1. Precision analysis Total Station vs. Laser Scanner

The result demonstrates that comparable precision to Total Station can be expected for the line-of-sight measurement, leading to conclusions for a further possible application: In comparing bi- and multitemporal point clouds, the strength in almost all methods of comparison is the detection of displacements along the normal direction. In case that there is a horizontal plane above a slope (e.g. in alpine regions), it is difficult to detect initial movement processes. By installing prisms in a sophisticated design, it is possible to detect horizontal movements in the range of a few millimeters. The absolute accuracy is determined using an EDM calibration line with superordinate accuracy. The maximum distance is 1200 m, which allows the derivation of longitudinal (range) and lateral deviations, but not of vertical deviations.

Table A1. Precision and accuracy of prism detection RIEGL VZ-i line – Values in [m]

	Precision[1]		Accuracy[2]	
	Single	Mean	Single	Mean
Lateral	0.0100	0.0021	0.0160	0.0030
Vertical	0.0080	0.0016	-	-
Range	0.0016	0.0003	0.0020	0.0004

… Surveying pillars and mounting

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.

[1]Precision, also called reproducibility or repeatability, is the degree to which further measurements show same results

[2]Accuracy is the degree of conformity of a measured quantity to its actual (true) value

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.

Fig. A2 & A3 illustrates how to design a stable mounting for the scanner including a protection shelter. 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. Thus, vibrations on the shelter caused by wind or other mechanical impacts cannot affect the scanner’s mount. Additionally, also power supply

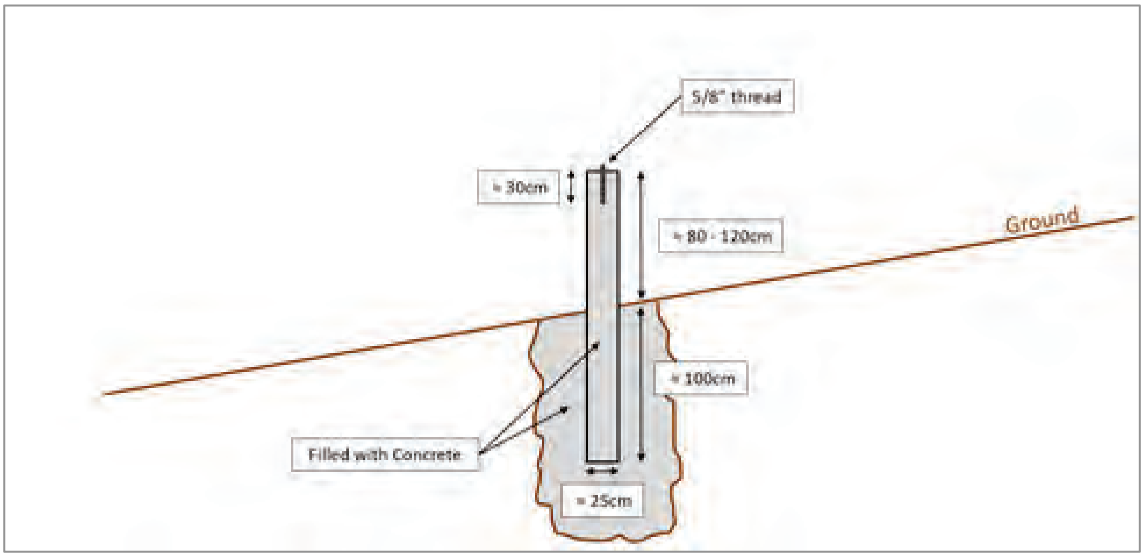


Figure A2. Example of a stable system setup – the pillar

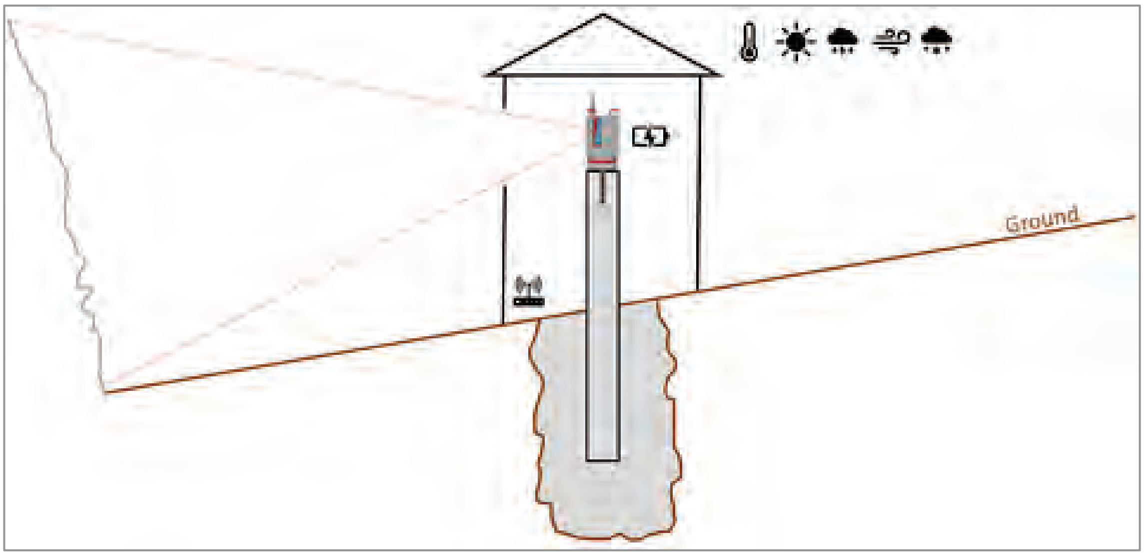


Figure A3. Example of a stable system setup with shelter must be available to run the scanner without interruptions as well as a stable internet connection for remote control of the scanner and data synchronization onto a server or the cloud.

Figure A4. System installation in Vals. pillar and shelter.

Best available conditions in projects are not available all the time. Installations using a rotating protective housing are also possible. In such cases, the communication unit as well as the power supply are stored in a waterproof box. Illustrated is an example of DMT during an installation in an open pit mine. The installation had a duration of 6 months and reliable operation was ensured.

Figure A5. Another mounting example from a DMT's monitoring project.

… Web-based Monitor+ App (Calculation & Formula)

For the visualization of changes between two data sets acquired at two different times (epochs), two of these 2D data sets (image in PNG format) are compared against each other.

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

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

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

$$=$$

586,612m

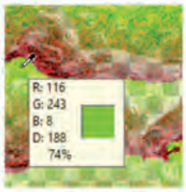


Figure A6. Range Coding in RGB image value

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

Figure A7. Calculate the local differences of each image pixel

The resulting change in range is change along the average normal vector of the two pixels (reference, comparison data set). As you can read from Fig. A8 positive values indicating longer range (material erosion), while negative values indicating shorter range (material accumulation).

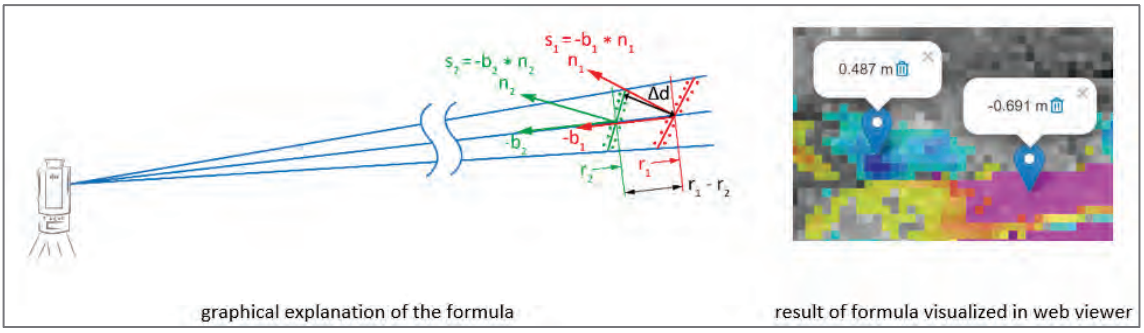
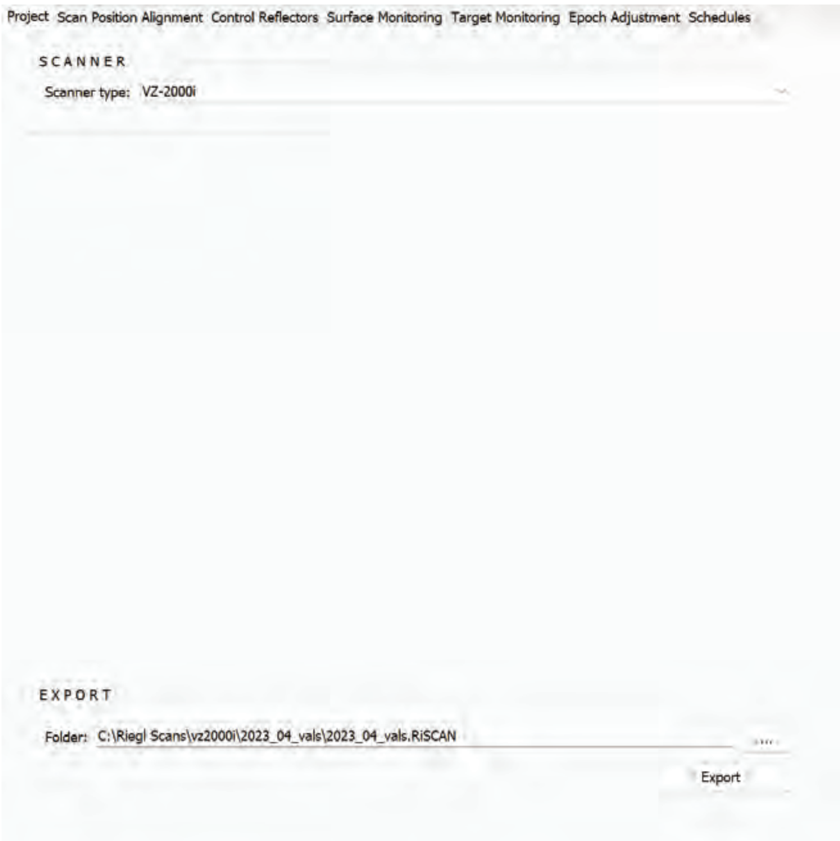
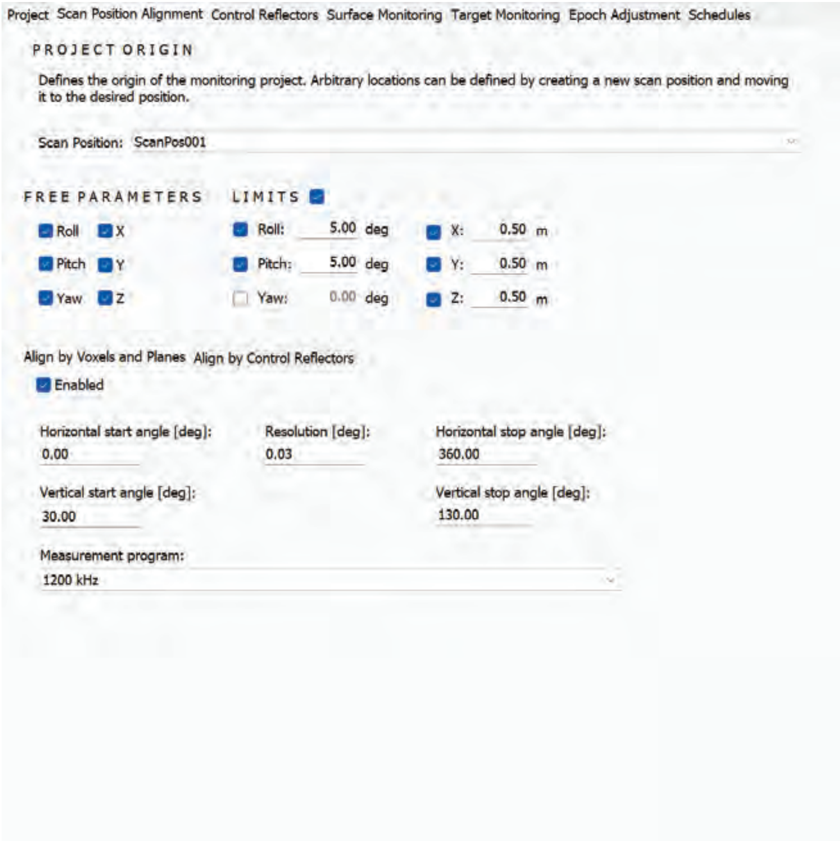


Figure A8. Surface differences calculated along the surface local normal vector

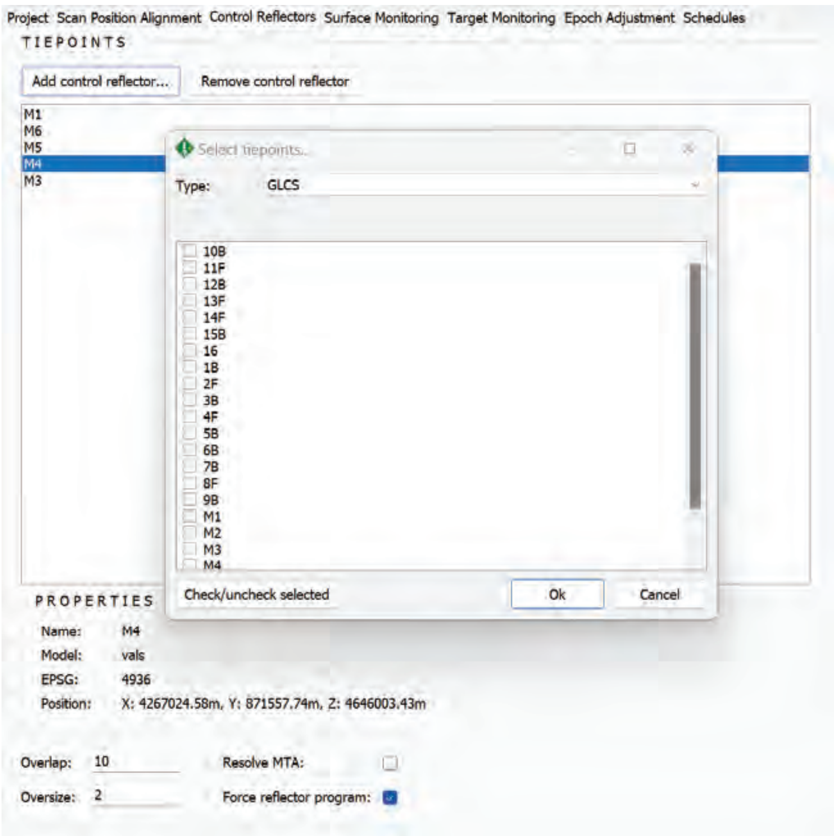
… RiSCANPRO Monitor+ App Configuration Wizard



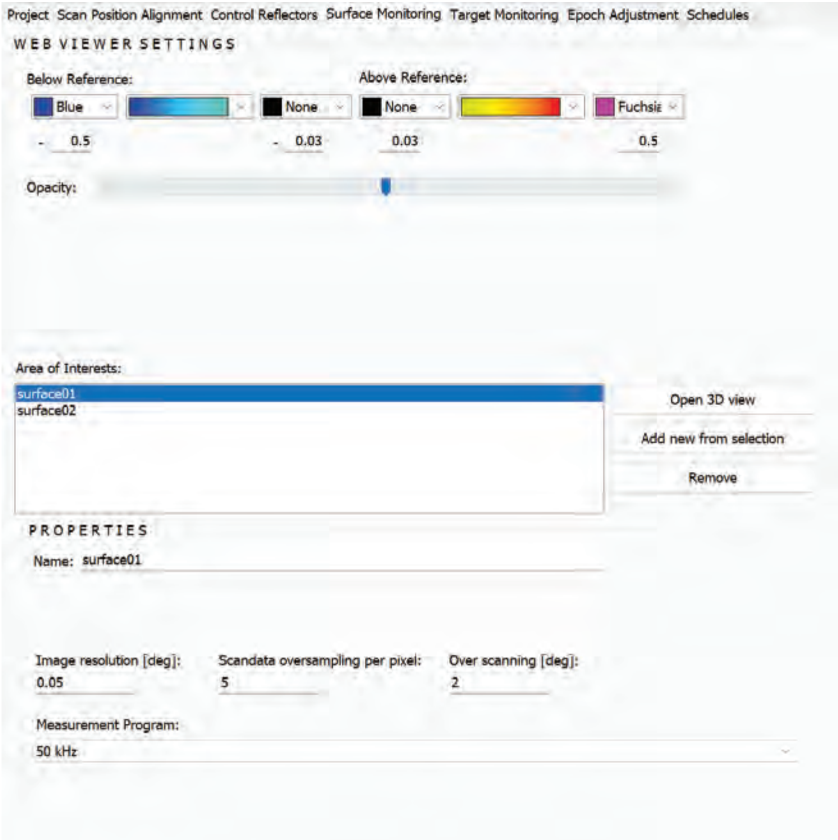
All files necessary for a correct configuration of the Monitor+ App, are stored within a single folder. The destination folder is defined by the path given in the field “Folder”. Finally, this folder has to be copied on the scanner to make it available for the Monitor+ App.



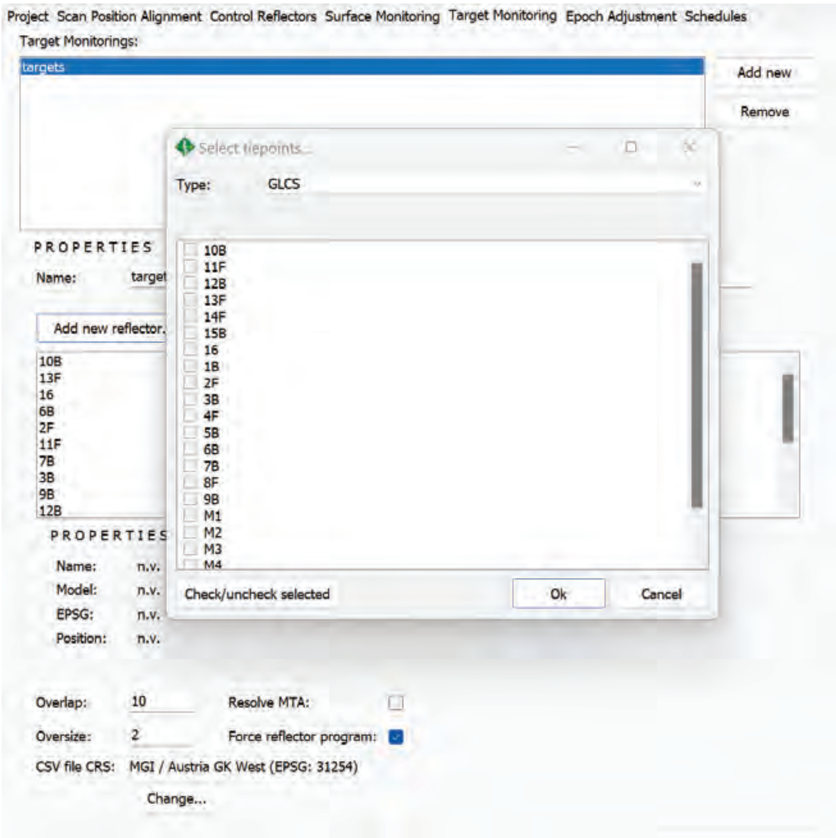
The position of the scanner from where the monitoring is performed must be aligned to the project origin. The project origin is defined by an existing registered scan position. Depending on how the scanner will be finally mounted for the monitoring the user can define free parameters and limits for the 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. On the scanner monitoring can be stopped at any time. Maybe the scanner is dismounted to be used for other purposes. Later the scanner is mounted again and monitoring is re-started on the scanner. Starting monitoring on the scanner always forces an alignment calculation.



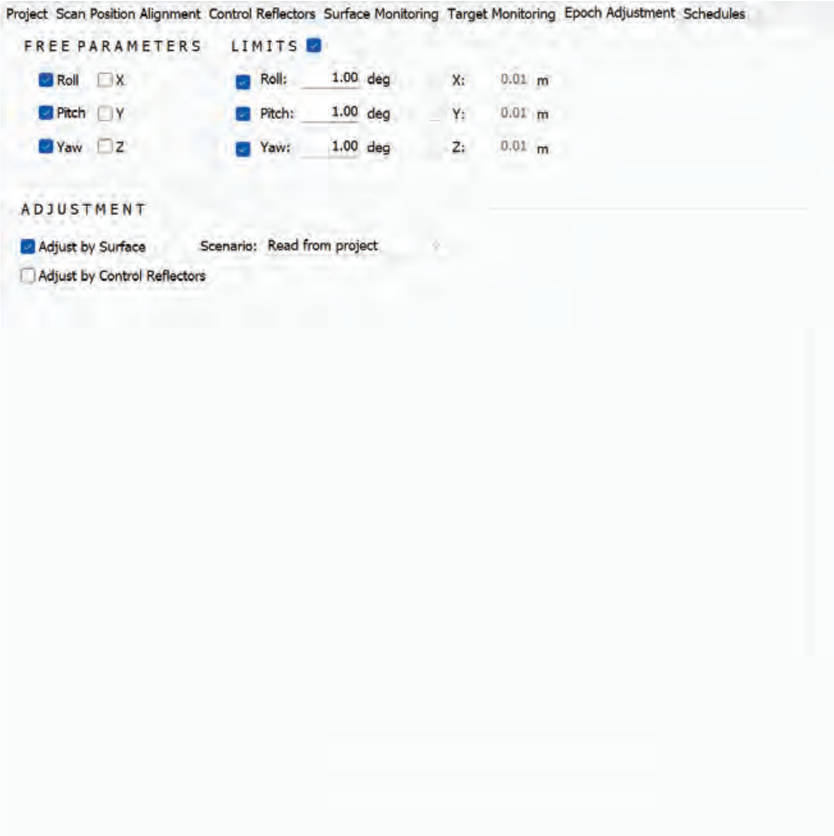
A set of control reflectors is defined. The source can be any tie point list within the project. Furthermore, settings for fine scanning of the targets are defined. The default value for Overlap is 10, and for Oversize is 2. These values fit for most cases. In case of fine-scanning prisms it is strongly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



Default threshold values and color tables for the visualization of surface differences are defined. An area of interest 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 default name for the AoI is derived from the horizontal and vertical field of view of the selected area. A number of different AoIs can be defined. Angular resolution and measurement program of the scan is defined in the lower section.



Sets of targets to be monitored are defined. Different sub-sets of targets for monitoring can 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.



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. In this example it is assumed that the position of the scanner is stable (x,y,z parameters disabled), while minor angular movements (limits of roll/pitch/yaw are defined by 0.1 deg) can occur. 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 (adjust by surface) or based on Control Reflectors.

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. Furthermore, the Epoch Adjustment method has to be selected. It is only available, if enabled on the previous page "Epoch Adjustment". Please be aware that "Adjust by Surface" is only available, if an AoI for surface monitoring is selected.

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.

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