WHITE PAPER

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

April 2022
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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 integration into risk management as an early warning system are 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 the spatial 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 was the 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 applications. These features make it practical to use the hardware within a monitoring system. Reliability is supported by the compact and robust design in a dustproof and splash-proof housing (IP64).

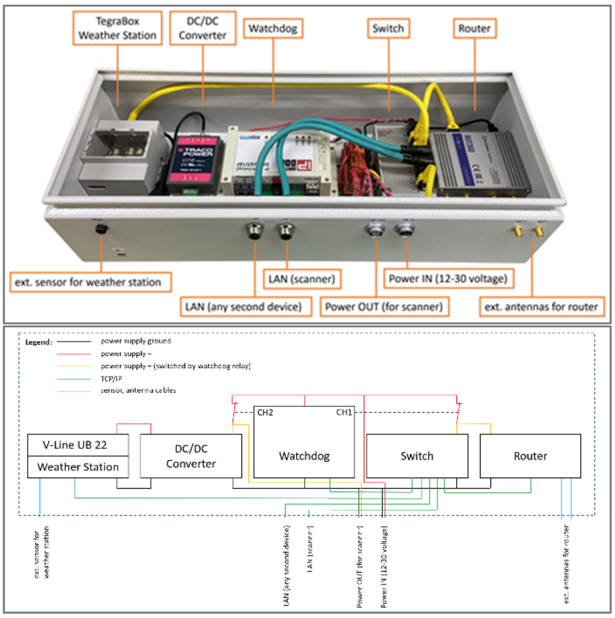

Figure 1. V-Line CB22 for *RIEGL* V-Line Scanner

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 a “communication-box”, which guarantees seamless 24/7 operation of the whole system (Fig. 1).

This box comprises a standard router to enable internet access. Besides the obligatory firewall settings for secure operation all necessary port forward settings pre-configured on the router. DDNS can be used if no static ip-address is offered by the network provider. Fig. 2 shows the software tool MobaXterm (https://mobaxterm.mobatek.net/), which can handle multiple communication sessions like FTP, SSH, VNC, etc. We use a VNC-viewer to establish communication with the graphical user interface of the scanner and SSH to communicate with its Linux shell. Also access to the scanner’s integrated FTP-server is possible. The user can, of course, run other software solution like putty for SSH communication, any FTP client software, and the *RIEGL* VZ-i series App as VNC viewer.

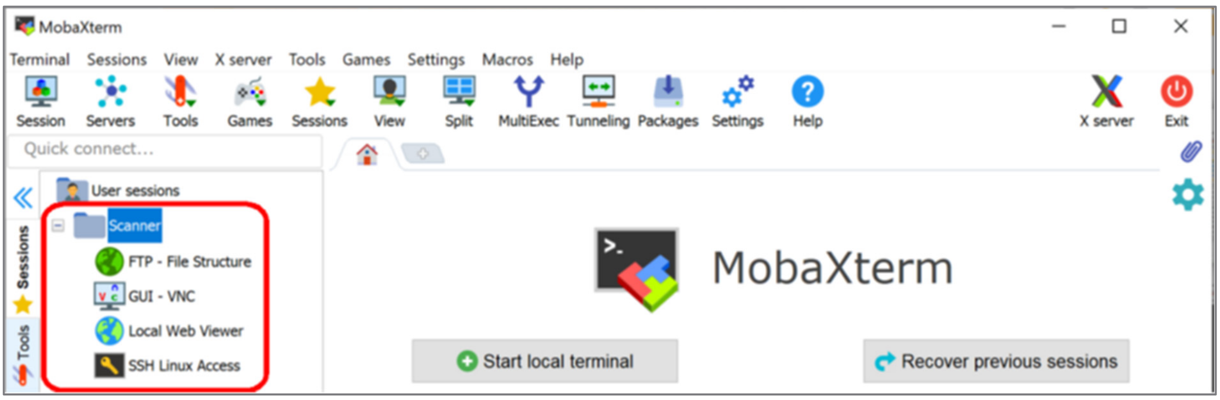

Figure 2. Software MobaXterm to establish multiple communication ports with the scanner

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.

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 measurement distance. Besides these properties it is essential that by using these prisms, a combination with other sensors is possible without any restrictions. This allows achieving a homogeneous georeferencing of all sensors within a monitoring project. 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 a detailed description of the functionality and a precise and accuracy evaluation.

Case study: Site description

Based on the latest developments at *RIEGL* and DMT, we demonstrate in this paper the comprehensive possibilities to integrate a laser scanner into your risk management by presenting an example project (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 3 campaigns in 2020 and 2021 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 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.

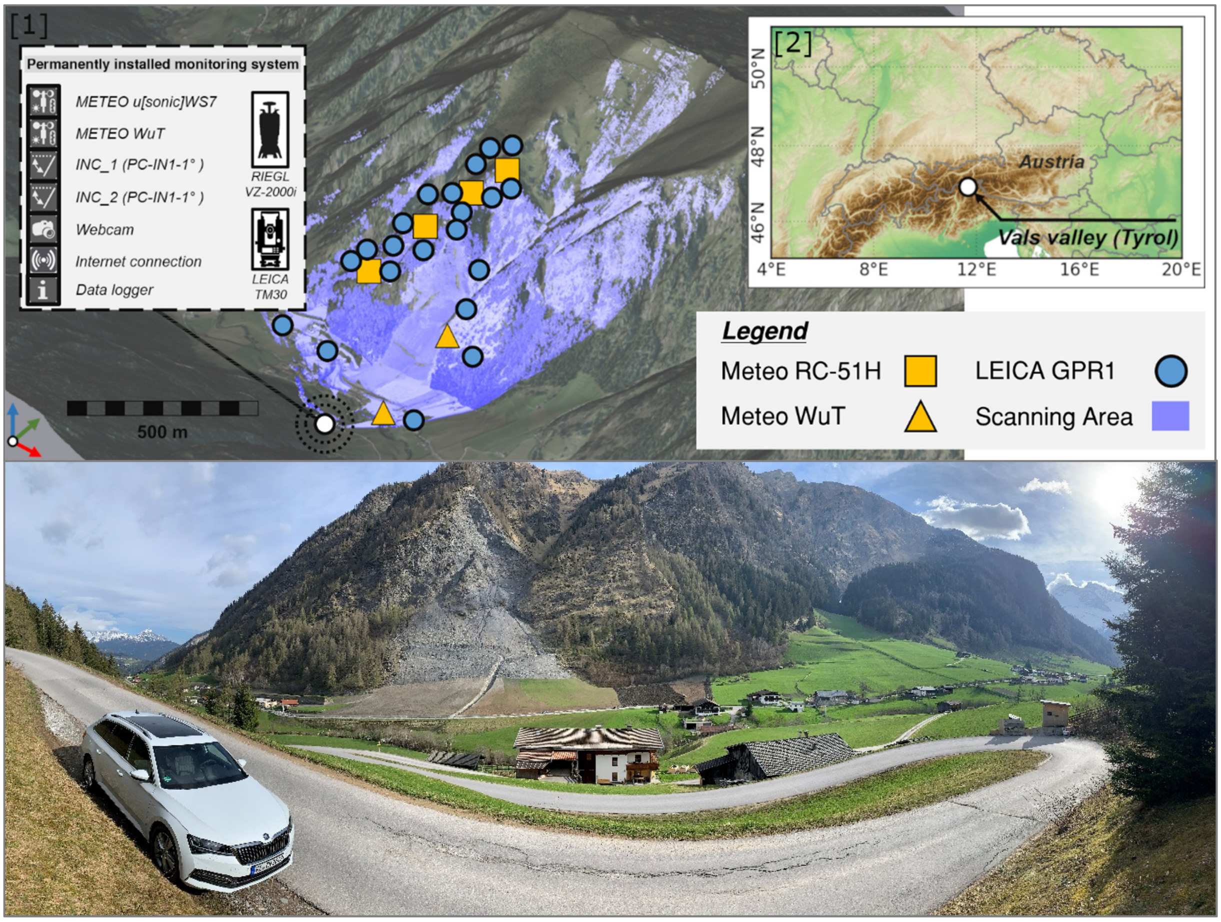

Figure 3. Three-dimensional overview of the test site in the Vals Valley including applied sensor technology and overview of the geographical situation of the Vals Valley. (Data Source: Land Tirol - data.tirol.gv.at [1] and http://ows.mundialis.de/

Case study: *RIEGL* Monitoring Workflow

Monitoring App

RIEGL developed a suite of so-called "mining 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 (Fig. 4). The mining apps are a bundle of apps – 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. In our case study the Monitoring App is used in order to detect potentially critical topographic changes. In the following we highlight in detail how the Monitoring 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.

For the Monitoring App, the user first defines general settings and a project name, followed by defining a scan pattern and a schedule for data acquisition. Finally, threshold values for data comparison and color tables for visualizing the resulting differences are defined. Fig. 5 shows an excerpt of the most important GUI pages of the Monitoring App. All mining apps include a scan scheduler, which allows even complex data acquisition schedules by utilizing the common crontab syntax. For more details please refer to https://en.wikipedia.org/wiki/Cron. The crontab in Fig. 5 shows a schedule acquiring a scan every three hours at the full hour. The comparison threshold values are set to 3 cm minimum and 50 cm maximum.

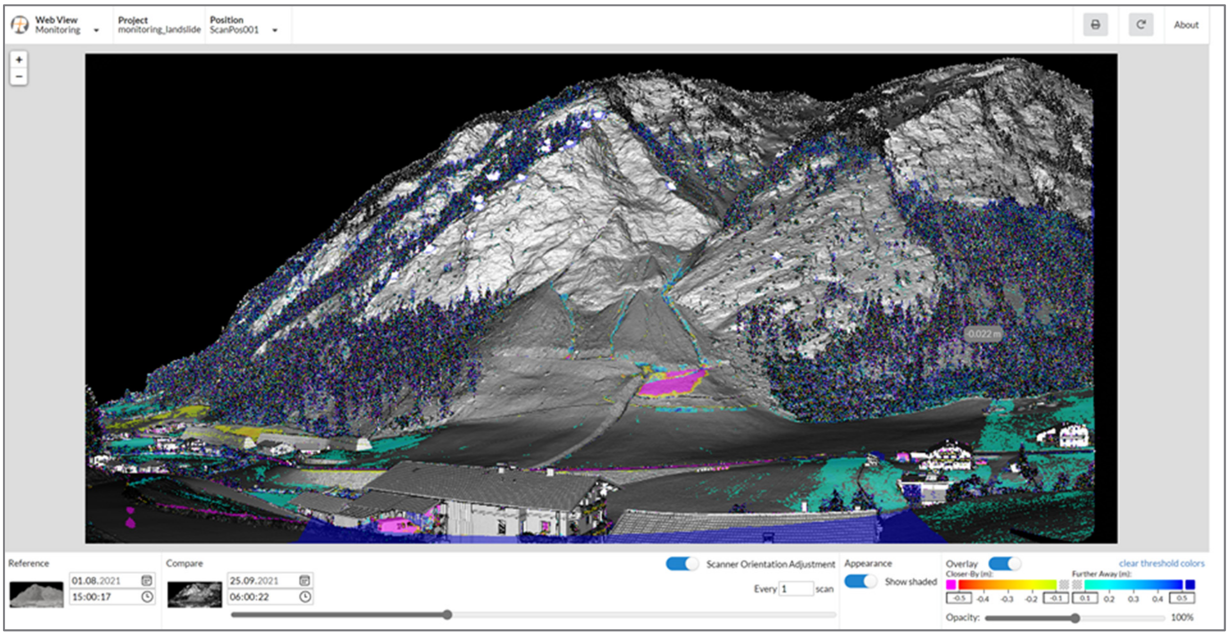

Figure 4. Web Viewer Monitoring App

Below the minimum threshold value color setting is on ”transparent”, meaning that no colorization is done. Above the maximum threshold value we simply define a single color – in this scenario pink. The defined threshold values and colors are used as default when opening the web viewer (Fig. 4). Even within the web viewer these threshold values and colors can be adopted. When re-opening the web viewer again the default values defined within the Monitoring App are used.

With each acquisition, the Monitoring 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 any small changes in the external orientation with respect to the first data set (Fig. 5 – General Project Settings / Orientation Correction enabled). 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 analysed to generate a 2D image with range and surface orientation information. For the visualization of changes, two of these 2D

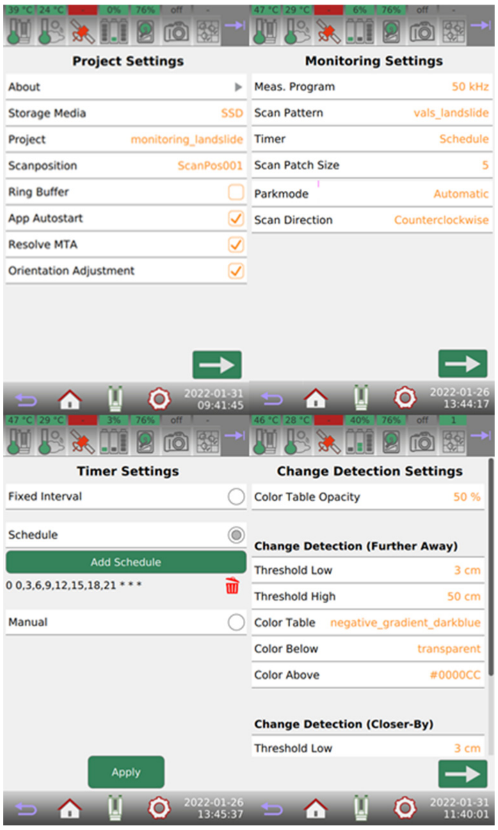

Figure 5. GUI Interface Monitoring App

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.

Monitoring Workflow

As already mentioned, installed corner cube prisms were monitored, besides monitoring the whole landslide by using the Monitoring App.

The Scheduler App is used for permanent monitoring of the prisms and runs in parallel with the Monitoring App. It is important to choose the scheduling of data acquisition within the app, so that they do not interfere with each other. To avoid interfering data acquisition it is necessary to define two separate schedules for fine scanning the prisms. Please see Fig. 6, showing the crontabs of both apps used for the data acquisition scheduling. Each crontab consists by definition of 5 entries, which are colored differently for a better visualization.

Monitoring App	Scheduler App
0 0,3,6,9,12,15,18,21 * * *	0,20,40 1,2,4,5,7,8,10,11,13,14,16,17,19,20,22,23 * * * 20,40 0,3,6,9,12,15,18,21 * * *
Acquiring a scan every three hours at the full hour	Fine-scanning of prisms three times a hour (0,20,40). On the hours, when Monitoring App is active fine-scanning of prisms only twice (20,40)

Figure 6. Crontabs for scheduling data acquisition

Data acquisition of a scan within the Monitoring App needs roughly 15 minutes and starts at the full hour. Therefore the Scheduler App can start the fine-scanning of the prisms 20 minutes after the full hour. Fine-scanning the prisms need 9 minutes, therefore it can be performed easily every 20 minutes. Fig. 7 shows the text file used for the configuration of the Scheduler App. A job is defined by a crontab schedule having at least one command to be executed. The command "FineScanTargets" is used followed by the path to the text file containing the necessary information to perform a fine-scan. Such a text file is automatically generated by the scanner, when running a reflector search on the scanner.

Finally, the script "compute-tiepoint-list-from-finescans" creates a text file containing the coordinates and further attributes of the fine scanned prisms. This data can be used to visualize diagrams showing possible movements of the prisms over time. Job 03 (see Fig. 7) shows the execution of the python script within the Scheduler App on a defined schedule (every 3 hours at the half hour). This python

```
scanschedulerapp.conf
[DEFAULT]
ProjectName = monitoring_landslide
ScanPattern =
MeasProgram = 1200 kHz
#CaptureImages = no
#CreateScanPos = no

[Job01]
Schedule = 0,20,40 1,2,4,5,7,8,10,11,13,14,16,17,19,20,22,23 * * *
FineScanTargets = /mnt/data/projects/monitoring_landslide.PROJ/controlpoints.tpl

[Job02]
Schedule = 20,40 0,3,6,9,12,15,18,21 * * *
FineScanTargets = /mnt/data/projects/monitoring_landslide.PROJ/controlpoints.tpl

[Job03]
Schedule = 30 1,4,7,10,13,16,19,22 * * *
Command = python3 /media/intern/scripts/compute-tiepoint-list-from-finescans.py
--crs EPSG::31254 --max-age 3h -t --quality 75 /mnt/data/projects/monitoring_landslide.PROJ
ScanPos001 /mnt/data/projects/monitoring_vals.PROJ/prism.csv
```

Figure 7. Configuration file for Scheduler App

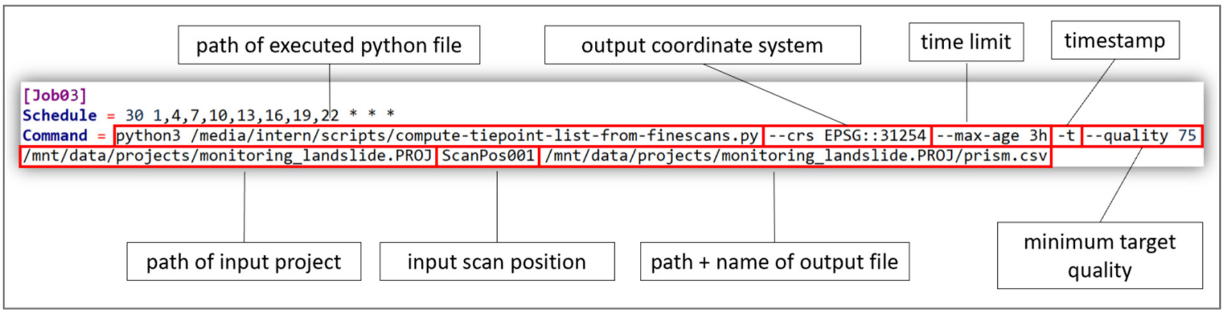

Figure 8. Optional parameters for script "compute-tiepoint-list-from-finescans"

script allows to define a number of optional parameters (Fig. 8).

As the project is registered, coordinates of the prisms can be delivered in any custom coordinate system (by EPSG code) defined within the geosys file on the scanner (see Fig. 8 – output coordinate system). The script is executed every three hours, why a time-limit is set to three hours (see Fig. 8 – time limit). The resulting output files are named “prism.csv”, a timestamp is also added to the name of the file (see Fig. 8 – timestamp). When fine scanning a target a quality attribute is generated in addition. If the quality drops under a certain limit (here 75%), this coordinate will not be written into the file (see Fig. 8 – minimum target quality). Such low quality can occur due to massive clouds, fog, rain, or snow while scanning. Omitting the data avoids misinterpretations that may lead to the detection of incorrect movements.

The Monitoring App calculates optionally a roll/pitch/yaw correction of the actual scan with respect to the reference scan. This correction is stored within the scan data. The “compute-tiepoint-list-from-finescans” script is analyzing the proper scan data (the scan data of the Monitoring App with closest time to the fine scanning of the target) and delivers besides the original coordinates also corrected coordinate values. This important feature allows handling slight movements of some millidegree of the scanner mounting caused by atmospheric inputs. Fig. 9 & 10 show that such a small impact can result in massive errors over a longer range.

The final csv files, with coordinates and ranges of the prisms, can be fed into any automatic prism monitoring system to visualize the acquired data in time diagrams.

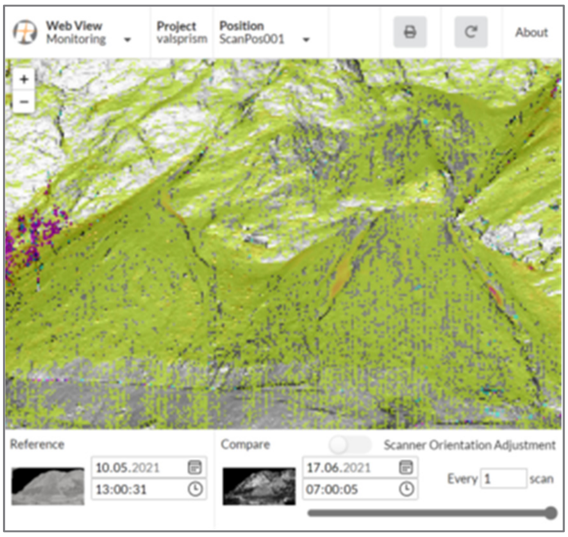

Figure 9. Monitoring App - Scanner Orientation Adjustment disabled

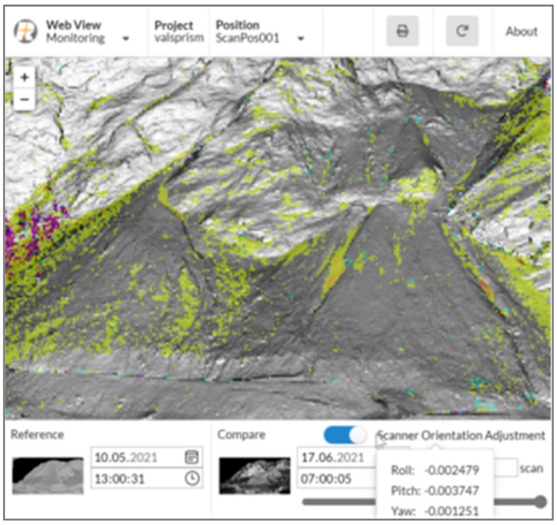

Figure 10. Monitoring App - Scanner Orientation Adjustment enabled

Data Synchronization

As described in the chapters before the whole system is designed to work 24/7 even in remote and harsh environments. Of course stable power supply for 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.

Data from scan acquisition and fine scanning of the prisms is stored on the internal SSD of the scanner, which provides almost one Terabyte of diskspace. One day (24 h) of data acquisition results for this setup of Vals (defined by scan pattern, number of prisms, schedules for data acquisition) in approx. 7 GB of raw data. The results derived from the raw data (data visualized on the web viewer of the monitoring app and coordinate-lists in csv format from the prism fine-scanning) consists only of 60 MB per day, beeing roughly 1 % of the raw data.

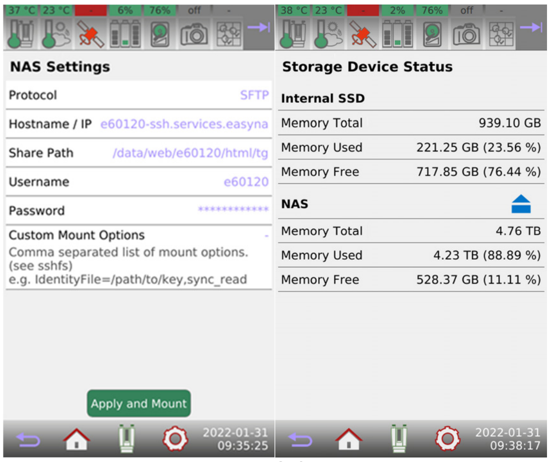

Figure 11. Mounting a NAS for data synchronization

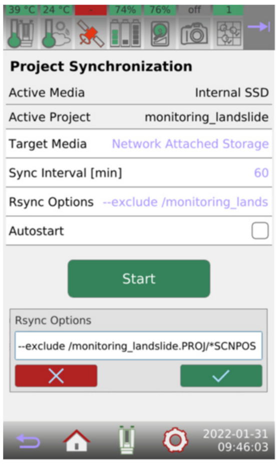

Figure 12. Rsync App for data synchronization

The scanner itself runs a web-server, which is utilized by the Monitoring App to publish the results. Nevertheless we recommend to synchronize at least the final result data to an external diskspace. This avoids lot of data, when many different groups of people view the Monitoring App data on their computers. Via the graphical user interface (GUI) of the scanner an external network attached storage (NAS) can be mounted (Fig. 11). Ideally, the NAS can be accessed from the internet and runs a web server for publishing the data. Depending on available the full raw data or only the 1 % result set could be synchronized. The Rsync App on the scanner allows data synchronization of an active project to a mounted NAS (Fig. 12). With the “Rsync Options” additional parameters for the Rsync command can be defined. The screenshot (Fig. 12) shows that all directories containing the scanned raw data are excluded from the synchronization.

Case study: Integration into customers risk management

Up to this point, the *RIEGL* Laser Scanner, the communication box and the software options for individual integration has been presented. Any user has the possibility to make their 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 of managing the scanning data in a central platform together with the data of other sensors and to generate additional information through combined use. 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 easily be collected in a common database, displayed online, analysed and archived. As an integral part of a professional risk management, DMT SAFEGUARD enables fast and informed decisions for any project phase.

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

DMT SAFEGUARD will be set up in a virtualized UNIX environment running at DMT's datacenter. The general system functionality is illustrated in Figure 13.

The web-application framework of DMT SAFEGUARD is based on two core components: backend and frontend, which are explained in the following.

DMT SAFEGUARD's WebGIS-Application is developed as a client framework for spatial data infrastructures. The software is implemented in JavaScript and Node.js and built upon Ext JS and OpenLayers.

Figure 13 and Figure 14 give an overview of the general system functions. DMT SAFEGUARD can connect to any sensor in the field. The system is directly connected to a GIS system providing map functionalities to visualize data and information in a geospatial context.

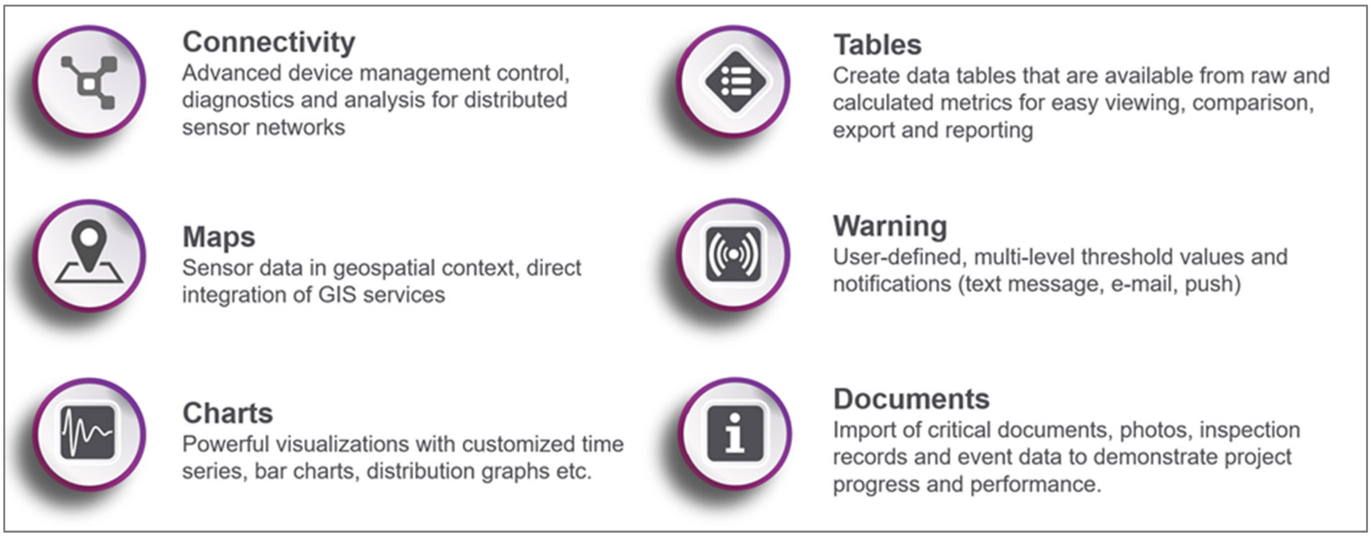

Figure 13. General function overview of the monitoring system

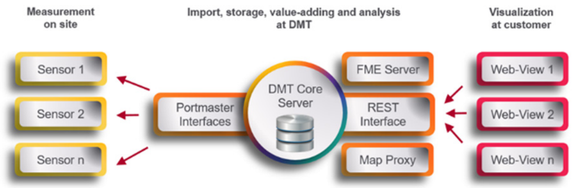

Figure 14. Dataflow from “Sensor” to User

All data can additionally displayed in customizable time series plots, bar charts, distribution graphs etc. The systems allows further to export data to the user’s local PC, for example tables of raw and calculated metrics for further local analysis. A key feature is the alert capability. Each data channel can be set up with user- defined multi-level threshold values. If threshold values are exceeded the system automatically sends out alert messages to a user group via e-mail or text notification. Furthermore project relevant documents (e.g. photos, inspection records) can be imported and distributed via the system in order to demonstrate project progress and performance. Map data is provided by an integration of the ArcGIS environment, including GeoServer and OpenLayers components for data handling and manipulation. Data charts are created using HighCharts modules and API. Figure 15 shows an illustration of the web view with background maps. Here, aerial images or open vector data can be integrated (e.g. Google satellite images and street maps) as well as relevant additional GIS data in Shape format. Sensor locations are shown directly on the map with their real position. Sensor status (e.g. in operation, error, missing data) is displayed via a traffic light colour scheme of the sensor icon. By a mouse click on the sensor of interest, an interactive measurement data chart is shown.

An example of the GIS layer functionally is shown in Figure 16. The illustration shows an area with various relevant data sources (e.g. subsidence zones, faults, ground elevation etc.) that are displayed if selected at the right-side list. The layer content with for example feature classification and color-coding is managed by the GIS backend and can be configured depending on project requirements.

A special feature of the system is the integration of dashboards, which allows flexible visualization of data in various forms and helps to query, visualize, alert on and understand your metrics (Fig. 17).

DMT SAFEGUARD LIDAR integration

The focus of DMT SAFEGUARD LIDAR is the integration of area-based sensor technology intending to provide all stakeholders with a range of advanced monitoring, measurement and analysis tools, which could be determining the impact of a rockfall in terms of ground and slope movements and supporting important

Figure 15. Illustration of the web application map view

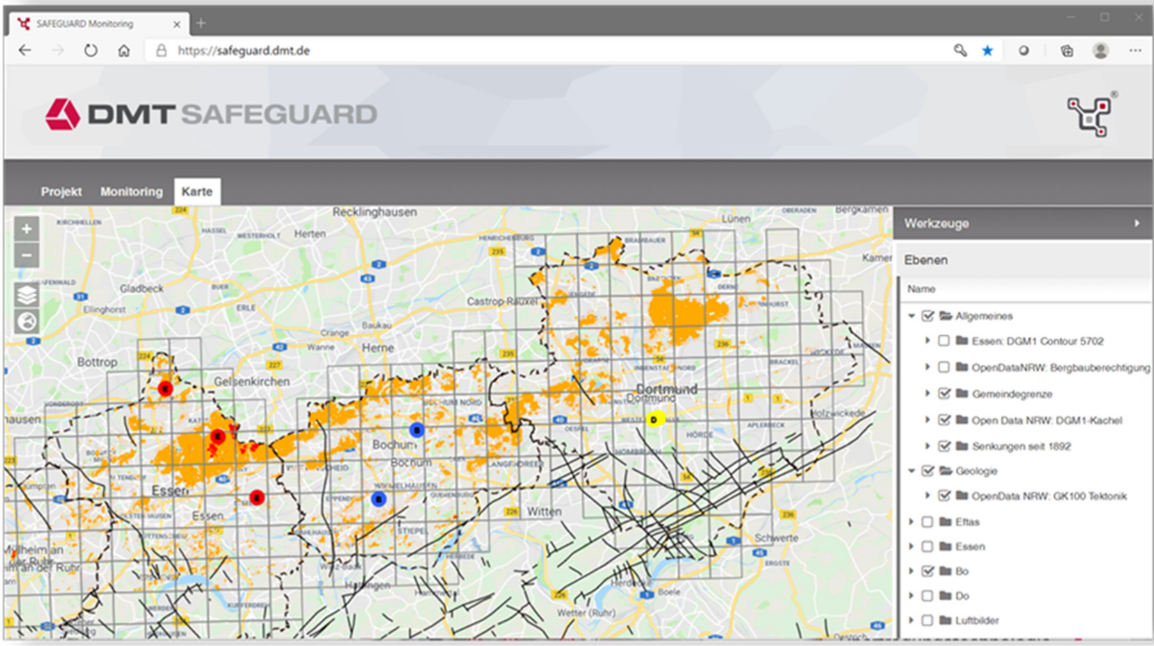

Figure 16. Illustration of application web view – GIS layer integration

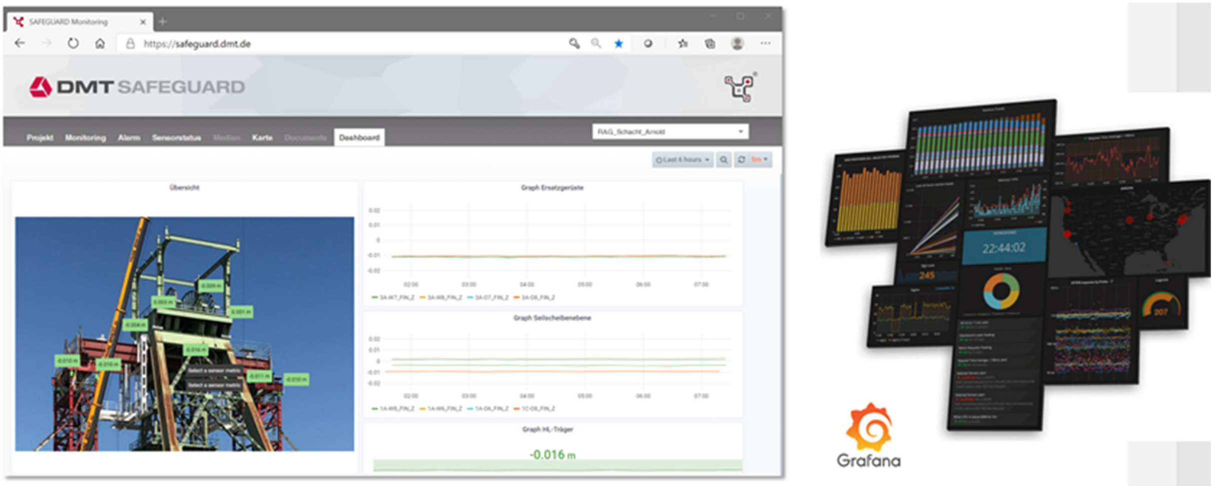

Figure 17. Illustration of application web view – Grafana data dashboard integration

information on the condition of the ground surface.

In this section we demonstrate in detail the data flow from the scanner to DMT SAFEGUARD. As described above, the scanner is set up and installed in the shelter on a pillar in the Vals Valley in Austria. The communication box 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 LTE connection. The data connection to the DMT servers is realized via a secure VPN connection (IPSec), so that the scanner itself is initially only available via the DMT network to selected users (e.g. HQ of *RIEGL* or customer networks). The scanner can be used worldwide and is available to many different users within a project.

DMT experts initialize the system and monitor its operation. After initialization, the scanner is able to operate and monitor automatically, alternatively scans can be started manually via the web application. Initialization of the measuring program includes the preparation of the *RIEGL* monitoring workflow, parameterizing monitoring app and scheduler app on the scanner. As a first result, the data of the

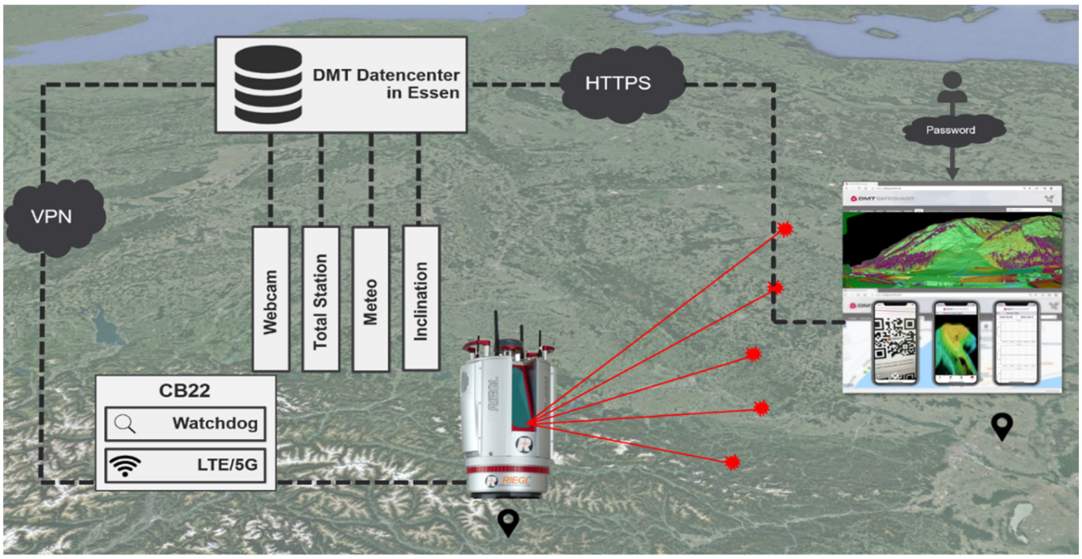

Figure 18. The installation of DMT SAFEGUARD LIDAR in schematic view

monitoring app and the time series of the prism detection are available on the scanner as CSV. In the next step, the data is synchronized to the servers in Essen using RSYNC via the secure data connection. The *RIEGL* Monitoring App is integrated into the DMT SAFEGUARD interface and is thus available to users from anywhere in the world via password protected login. There is no necessity for a separate link to the scanner. Dashboard functionality in DMT SAFEGUARD enables intuitive and interactive visualization of time series from prism detection. In addition, all sensors can be displayed in spatial context on a map.

Table 1. Applied sensors and their measuring frequency

Data	Sensor	Acquisition interval
3D point cloud of rockfall area 3D point cloud of each prism	*RIEGL* VZ-2000i	Meas. prog. interval of 180 min • Areal scan (15 min) • 21 prism scans (Every 20 minutes)
3D meas. to each prism	LEICA TM30	Every hour
Inclination of the pillar	POSITION CONTROL PC-IN1-1°	Every 15 sec
Air temperature Air pressure Rel. Humidity	WIESEMANN & THEIS (WUT) WEB-THERMO-HYGROBAROMETER 57713	Every 15 sec
Air temperature Relative Humidity	ELITECH TEMPERATURE-LOGGER RC-51H	Every 15 min
Air temperature Air pressure Rel. Humidity Wind speed Wind direction Global radiation Dew point	LAMBRECHT U[SONIC]WS7	Every 15 sec

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

In Vals lidar data is complemented by integrating various inclinometers, a total station, weather stations and a webcam via SAFEGUARD (see Table 1).

The case study is available as a demo:

https://safeguard.dmt.de/riegl

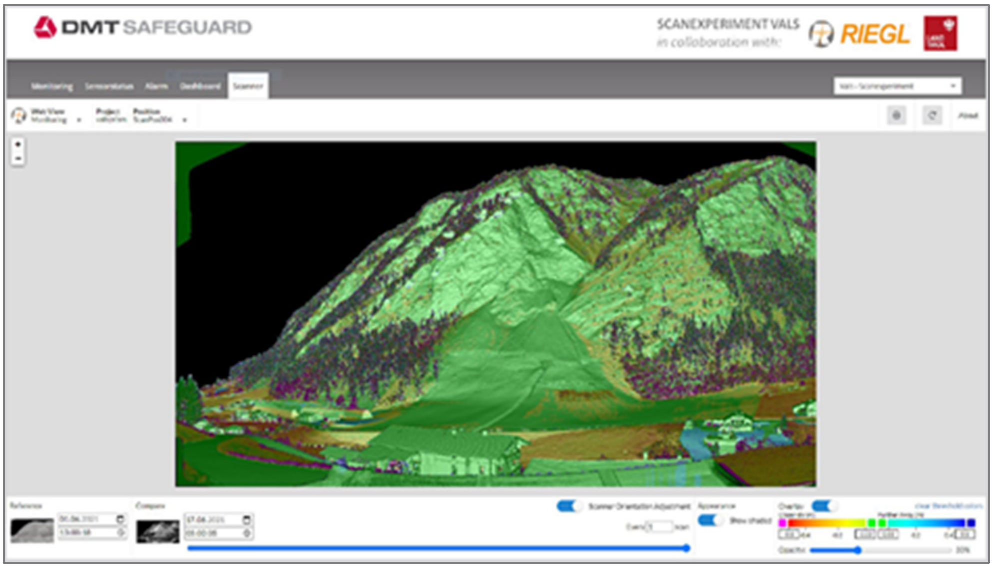

Figure 19. *RIEGL* Monitoring App integrated in DMT SAFEGUARD

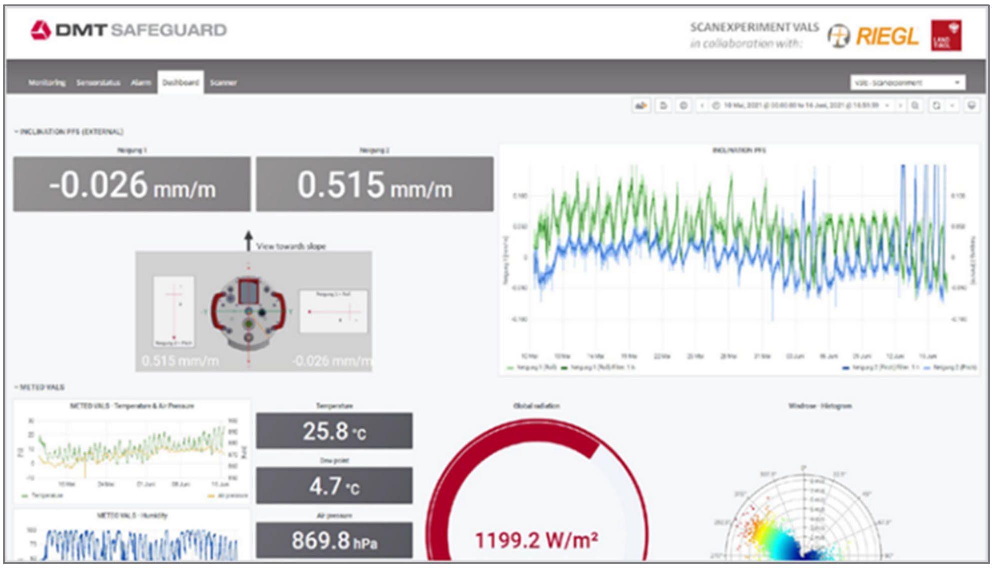

Figure 20. Visualization of the inclination sensor system together with the weather data in DMT SAFEGUARD

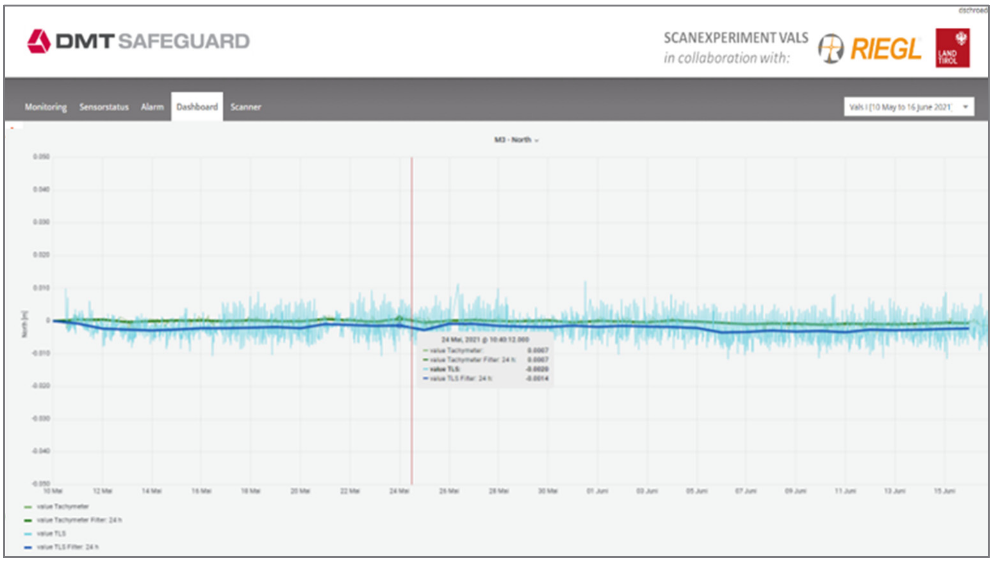

Figure 21. Plot of prism detection time series. Total station and laser scanner homogenized in one dashboard.

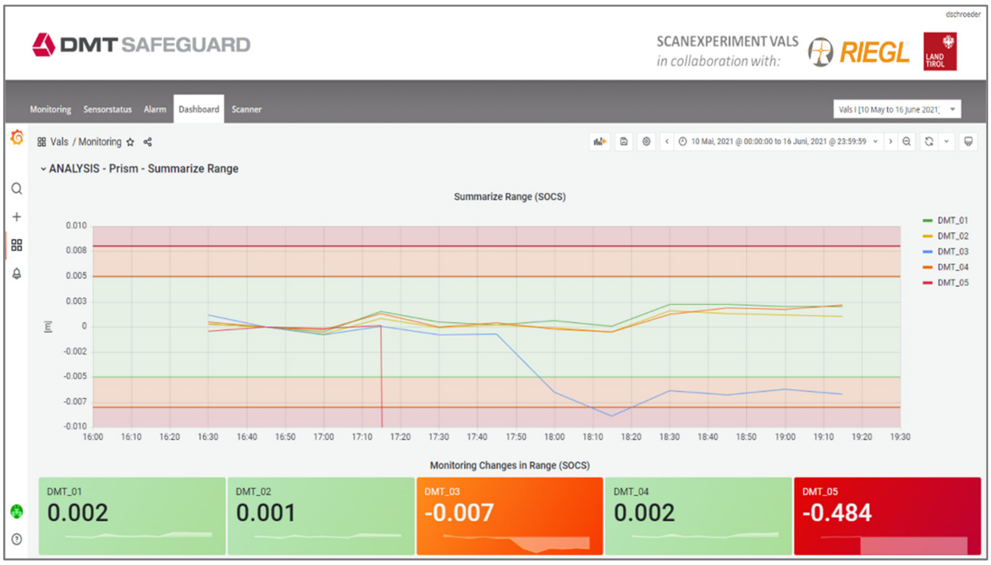

Figure 22. Plot of prism detection time series. Alarming on range differences.

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. Real-time documentation options, document management, an automated real-time assistance system and sophisticated reporting complete the service for you.

Conclusion

The open architecture of the *RIEGL* VZ-i Series scanners allow 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, demonstrating its high degree of flexibility.

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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).

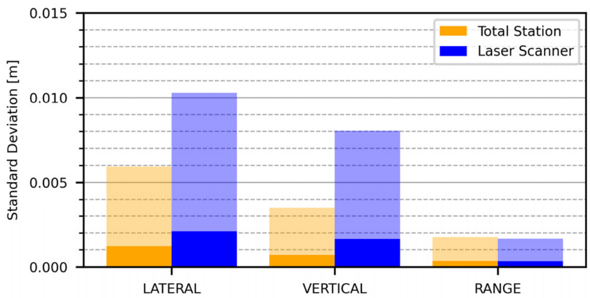

Figure A1. Precision analysis Total Station vs. Laser Scanner

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. Vibrations on the shelter caused by wind or other mechanical impacts cannot affect the scanner's mount. Additionally also power supply must be

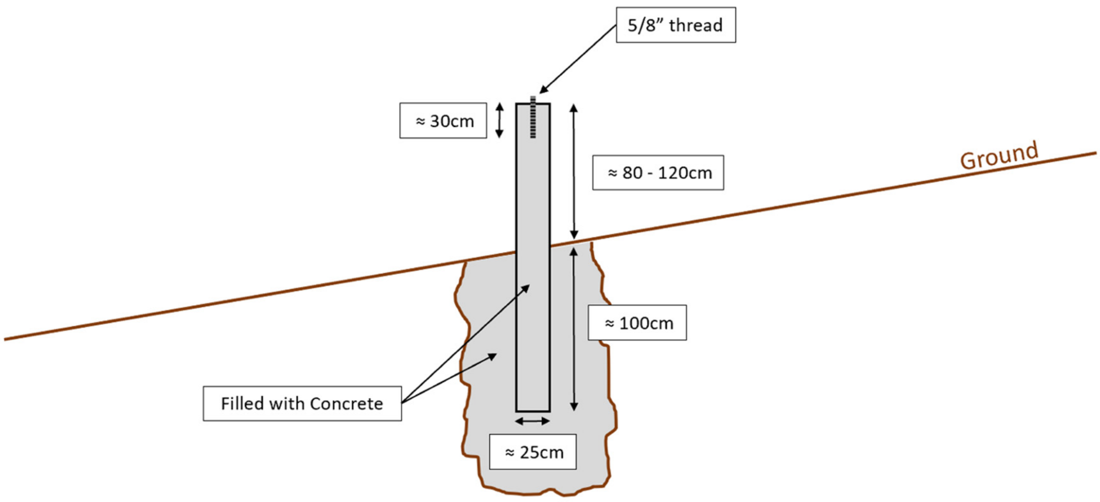

Figure A2. Example of a stable system setup – the pillar

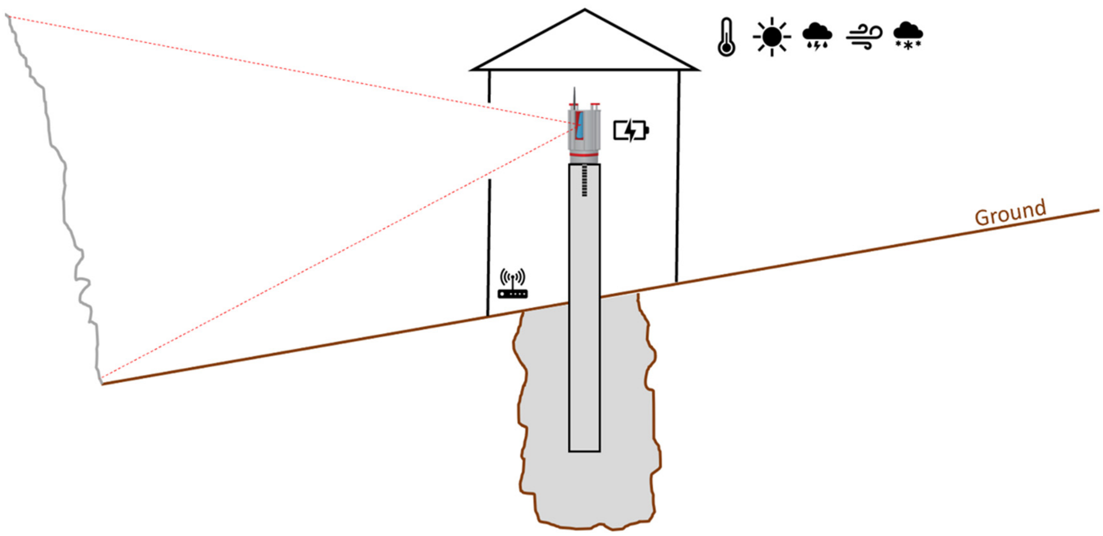

Figure A3. Example of a stable system setup with shelter available to run the scanner without interruptions as well as a stable internet connection for remote control of the scanner and data synchronization onto a server or the cloud. How to run the scanner remotely and realize data synchronization will be explained in detail in the following chapters.

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.

… Webbased Monitoring 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).

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

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

$$=$$

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

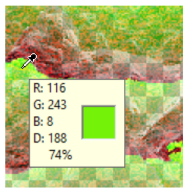

Figure A6. Range Coding in RGB image value

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).

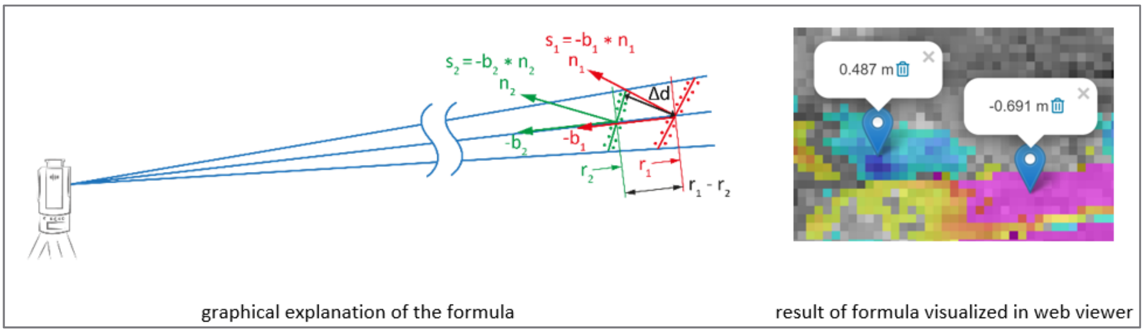

Figure A8. Surface differences calculated along the surface local normal vector

RIEGL Laser Measurement Systems GmbH

RIEGL is an international leading provider of cutting edge technology in airborne, mobile, terrestrial, industrial and unmanned laser scanning solutions. *RIEGL* has been producing LiDAR systems commercially for over 40 years and focuses on pulsed time-of-flight laser radar technology in multiple wavelengths. *RIEGL*'s core Smart-Waveform technologies provide pure digital LiDAR signal processing, unique methodologies for resolving range ambiguities, multiple targets per laser shots, optimum distribution of measurements, calibrated amplitudes and reflectance estimates, as well as the seamless integration and calibration of systems. *RIEGL*'s various 3D scanners offer a wide array of performance characteristics and serve as a platform for continuing "Innovation in 3D" for the LiDAR industry. From the first inquiry, to purchase and integration of the system, as well as training and support, *RIEGL* maintains an out-standing history of reliability and support to their customers. Worldwide sales, training, support and services are delivered from *RIEGL*'s headquarters in Austria, main offices in the USA, Canada, Japan, Australia. UK and China, and by a worldwide network of representatives.

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V1.0 13.04.2022