Innovative Edge Computing Technology for Autonomous Monitoring Systems

Lidija ŠPIRANEC and Elias NIEL, Switzerland

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SUMMARY

The need for permanent 24/7 monitoring has been rapidly growing in the last decade. Be it in developing urban areas, open-pit mines or areas with possible natural hazards, today, more than ever, safety comes first. Deformation monitoring provides information about movements and allows immediate informed decisions based on data.

Every automatic monitoring system consists of four components: monitoring sensors, power supply, communication device and monitoring software. The biggest threat to permanent monitoring systems is missing data or data losses. This means if any of the system's components malfunction, data would not be gathered and there would be no information about the monitored object during the downtime, which can pose a severe safety threat. The most frequent causes of data loss are communication or power failure, data server failure and environmental effect on the measurements. Therefore, to ensure the utmost reliability of the monitoring system, the field components must operate intelligently and autonomously.

This paper will present how the latest technological advancements in Leica Geosystems' monitoring solution ensure continuous and uninterrupted dataflow. The new Leica TM60 is a self-learning monitoring total station, specifically built for the purpose of 24/7 monitoring and using the ATRplus technology. Due to its robustness, it also has the longest maintenance intervals among total stations, thus providing the longest continuous operation in the field. The TM60 is controlled by Leica GeoMoS Edge, the new monitoring software component embedded on communication devices in the field. Its functionality is to perform the configured measurement cycle, compute the raw measurement data quality and, based on it, trigger the repeated measurements and finally, to deliver the measured data to the monitoring office software – Leica GeoMoS Monitor. Data transfer is realised by using the EdgeConnect technology, powered by Hexagon's Xalt, which enables secure cloud IoT connectivity between the field and the office.

Robustness and resilience of the highest quality monitoring solutions can be attributed to reliable edge computing technology. Monitoring sensors and software must cooperate and be able to adapt to any change in the environment to achieve the ultimate goal of preventing data loss. Only when data is available, the hazard of the monitored object can be ascertained.

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1. INTRODUCTION

Automated geodetic monitoring systems have been utilized for over 30 years (Brown, Kaloustian, & Roeckle, 2007). The rapid pace of world development requires higher safety standards than ever, therefore the need for automated monitoring systems is also in constant growth. Whether it is monitoring for construction or maintenance purposes, protection against natural hazard threats, ground stability in the mining industry or structural health analysis, only when the monitoring data is in real-time data can it truly allow for informed and quick decisions. Hence, insufficient data or the complete lack of data, whatever its cause may be, can pose a severe safety threat if unforeseen movement occurs.

Similar to the four elements of nature, there are typically four components of automated monitoring systems:

- Monitoring sensors: responsible for generating raw measurements within defined intervals. They can be geodetic sensors (e.g. total stations, GNSS, levels), geotechnical sensors (e.g. tilt meters, extensometers, piezometers), environmental sensors (e.g. weather stations) or remote sensing sensors (radars, InSAR)
- Power supply: provides power to on-site equipment. The power source must be 24/7 operational with the availability of a fallback solution (usually a battery). Examples of power supplies include mains electricity, solar panels and generators.
- Communication device: enables near-instantaneous data transfer between the field and the office. Regardless of whether the monitoring system is connected to the internet, or is only operating within a local area network, communication devices (usually industrial routers) represent the bridge between the sensors and monitoring software.
- Monitoring software: responsible for the processing of measured data from the field sensors, it provides near real-time information about movements. Monitoring software must be able to automatically detect and inform about displacements outside of defined thresholds, as well as provide the overview of historic data to visualise and analyse movement trends.

Each of these components carries its own complexity and can malfunction in its own way, but only if all components are seamlessly integrated into the monitoring system, the probability of data gaps can be reduced to a minimum.

This paper presents how the latest technological advancements in Leica Geosystems' monitoring solution (Figure 1) ensure continuous and uninterrupted dataflow:

- Leica TM60: a total station specifically built for the purpose of 24/7 monitoring. Its technical solutions and robustness allow for highest measurement success rate with the longest maintenance intervals among total stations.
- Leica GeoMoS Edge: the edge computing technology, which is responsible for the autonomous execution of the measurement cycles and local data storage in case of communication failure.
- EdgeConnect technology, powered by Hexagon's Xalt: technology which enables secure IoT connectivity between the monitoring sensors in the field and the Leica GeoMoS Monitor monitoring software.

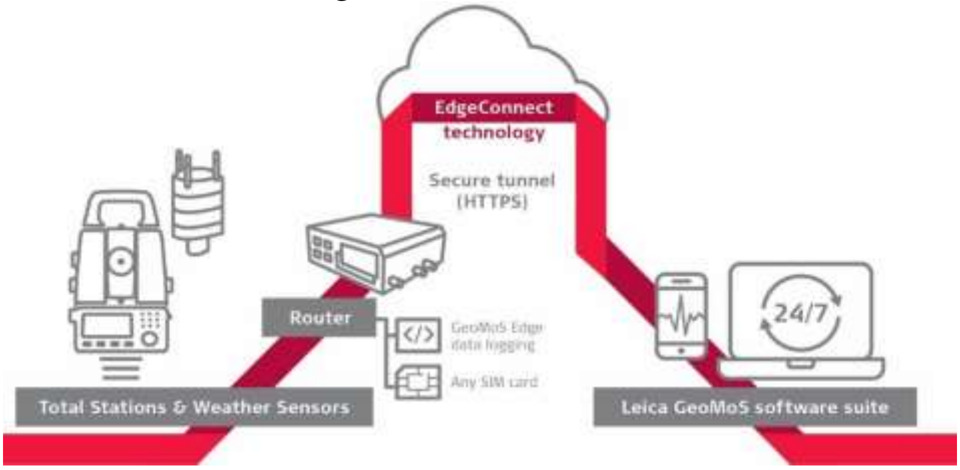

Figure 1 Leica Geosystems monitoring solution

2. AUTONOMOUS MONITORING SOLUTION

An autonomous monitoring solution refers to a monitoring system which continues being fully operational in case of communication or power failure, or both. While failures of the main power source can easily be overcome by having a secondary power source (e.g. internal or external battery, generator), communication failure implies that the execution of the measurement cycles must proceed without the feedback from the monitoring software. Therefore, the equipment in the field must possess its own intelligence, in order to be able to autonomously proceed with data acquisition and adapt to potential changes in the environment.

2.1 Monitoring Total Station

The new Leica TM60 (Figure 2) is a self-learning monitoring total station, that can adapt to the environmental conditions and automatically measure targets farther away than traditional surveying total stations. It is equipped with the latest Leica Captivate onboard software, where environmental specific configurations do not have to be set. This allows to speed up the measurement frequency in monitoring applications and decreases the number of bad or failing measurement attempts as it automatically adapts to changing environmental conditions, which can happen during regular monitoring cycles.

This is possible with the image-based ATRplus technology for target recognition and measurements. It consists of an active laser source in the telescope, which emits a coaxial infrared beam that will be reflected by the target. A CMOS sensor, functioning as a passive receiver unit in the telescope detects the reflected signal, which is appearing as a light spot on the camera sensor (Figure 3). In the first step software algorithms analyse and process this image to classify the light spot as a surveying target. Hence the emitted laser energy is varied and regulated to improve the spot quality on the CMOS sensor in terms of saturation and sharpness. This is based on the distance, and moreover the environmental conditions, which have a big influence on the laser beam. During this process the parameters, which used to be configured by the "visibility settings" in the predecessor of the TM60 – the TM50, are derived and automatically applied by the self-learning ATRplus. Thus, the user does not have to decide between "Good", "Rain & Fog" or "Sun & Reflection" to get the best performance for the automatic target recognition (Grim et al., 2015). The Leica TM60 is the first monitoring total station using this technology.

Figure 2 The latest monitoring total station, Leica Nova TM60

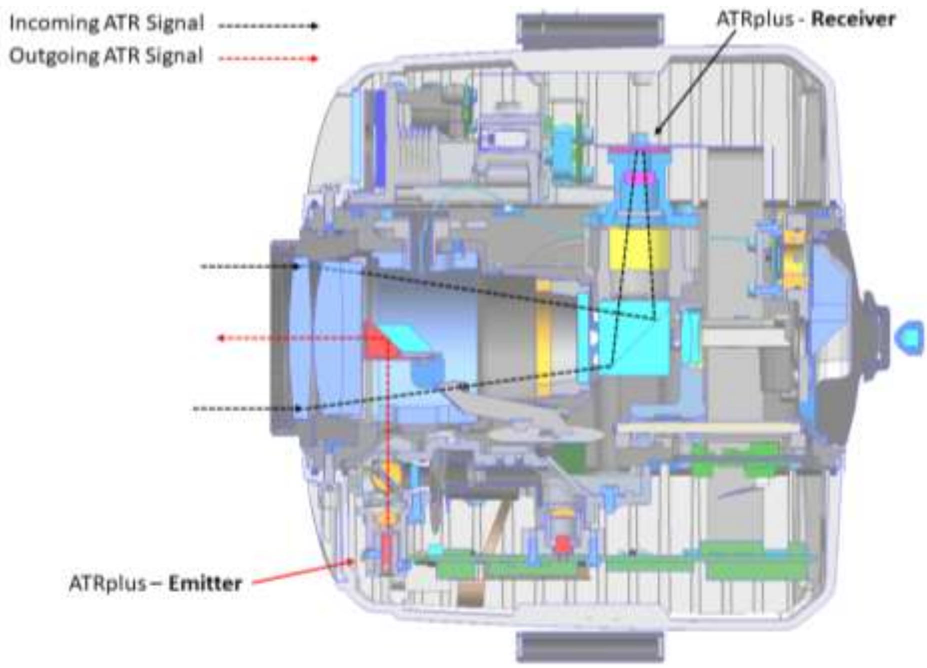

Figure 3 Optical path of ATRplus signals inside the TM60 telescope

Additionally, also non-target reflections can be detected and rejected. To reject a foreign signal, such as headlights or bright sunlight, which might appear within the field of view of the telescope, the ATRplus technology uses the so-called "BiDi-Mode" during the target search. This mode regulates the laser emitter in such way, that alternating bright- and dark images can be recorded by the receiver. An active foreign light source (e.g. sunlight – not only direct, but also deviated through mirroring effects of metal, water, or windows) appears the same in both kinds of images, however a passive reflector, like a monitoring prism appears differently in the respective images (Figure 4). This enables that similar light spots on the CMOS sensor can be classified as correct monitoring prisms.

Figure 4 Bright (left) and dark (right) ATRplus image of a car and a reflective prism

While ATRplus has been well established in classical surveying total stations and MultiStations, it is now also available for long-range measurements up to 3000 meters in the TM60 monitoring total station. This is achieved with a special lens system focusing the emitted laser energy in a narrow beam, allowing longer measurement ranges. This comes with a smaller field of view for automatic target aiming which can be an advantage when having multiple prisms close to each other in a far range. The Leica TM60 also can measure prisms with an angular accuracy of 0.5”. This is achieved by the combination of a quadruple head angle-measurement system on the Hz- and V-Axis, an internal inclination sensor and the automatic target measurement of the ATRplus. Crucial is the possibility of determining the centre of the light spot on the CMOS sensor with sub-pixel accuracy. This centre point is then known in pixel coordinates of the CMOS sensor which then are applied with the known sensor-offsets to the centre of the optical axis.

The Leica TM60 is also equipped with a Piezo-Drive system. This ensures smooth long-term operation, reliability and stability independent of the surrounding conditions (Grimm et al., 2013). The distance measurement module is based on the traditional and highly accurate phase-shift comparison technology – the Leica PinPoint distance measurement system. Additionally, the Imaging variant of the Leica TM60 is equipped with an overview camera and an on-axis camera in the telescope suitable for camera based aiming (“see what the total station sees”), for photo documentation as well as the possibility to perform photogrammetric tasks in post processing.

Automatic point learning (AutoLearn) is another monitoring-specific innovation for total stations. It enables all targets in a defined area to be rapidly detected, measured and learned. This feature is available only for the Leica TM60 instruments and it is particularly important during the first setup of the monitoring system, but also when additional prisms are being installed. Automating point learning is a big step forward in geodetic monitoring because human errors, like omitted points, are eliminated by using ATRplus technology.

AutoLearn is utilized through the GeoMoS Monitor software. The simplest procedure to learn new points is by using the cameras on the instrument; either the overview camera or the telescope camera with 30x magnification. The live video stream from the camera can be used to position the instrument in the wanted direction. In the next step, an image of that area is captured and a rectangular search area is drawn on the image. Next, the TM60 performs a search within the defined area (Figure 5), according to the preconfigured settings. Once the search has been completed, there is a report of the number of prisms found in that area and the number of prisms which are new in that monitoring project. In the case of using a TM60 variant without cameras or when measuring in darkness, AutoLearn can still be performed based on the angular values (azimuth and vertical angle) of the extents of the search area. The prerequisite of this is that the instrument's orientation must be known.

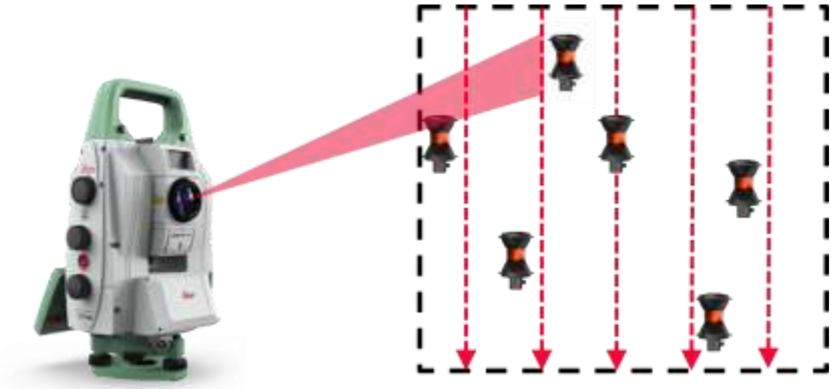

Figure 5 Leica TM60 conducting the prism search within a defined area. The configuration was done using GeoMoS AutoLearn feature.

2.2 Edge Computing in Monitoring

The software component of most monitoring systems is usually a standalone or cloud deployment of the specialized monitoring software, which acts as a server. Having a direct communication between the sensors and the server allows many benefits, including repeated measurements of points and real-time warnings where the defined limits were exceeded, but it also displays weakness in its dependency on stable communication component. This means that with every communication outage, measurements cannot be carried out, which produces data gaps and therefore becomes a safety threat. For that reason, monitoring systems must be able to run autonomously for a certain period of time, to persevere with data acquisition. This, however, is not a permanent solution, as complete detachment from the server also has a consequence of losing real-time information and notifications in case of detected movements.
GeoMoS Edge provides the autonomous solution, by having the data acquisition component replicated from the server and embedded on a communication device. Its functionality is to perform the configured measurement cycle, compute the raw measurement data quality and, based on it, trigger the repeated measurements and finally, to deliver the measured data to the monitoring office software – Leica GeoMoS Monitor. GeoMoS Edge currently supports Leica total stations, MultiStations and weather sensors. Leica total stations can perform prism

measurements, as described in (Lehmuller, 2016), reflectorless measurements and take images with defined schedules, while MultiStations can also automatically scan predefined areas, as described in (Wöllner, 2017). Weather sensors cater for general information about environmental conditions, but also provide crucial data for meteorological corrections of total station slope distance measurements.

Figure 6 Measurement process with GeoMoS Monitor and GeoMoS Edge

The workflow (Figure 6) starts with configuring the measurement cycle in Monitor, which then sends the configuration to GeoMoS Edge. In case of communication failure, data acquisition will persist autonomously, based on the last available configuration and measurements will be stored locally until the communication with the server (GeoMoS Monitor) is restored. This means that data gaps due to communication failure are eliminated.

2.3 Secure Data Transfer

Communication protocols between the field and the office must fulfil the highest security requirements, due to the sensitivity of monitoring data, as well as the overall security of the local network the server belongs to. This can be achieved with special IT configuration, which typically requires involvement of IT experts. A secure communication is achieved using either VPN technology or by configuring firewall settings (static IP address, inbound and outbound rules in the PC and the communication device). This process adds complexity to the monitoring installation, which can make it costly and time consuming, therefore increasing the time until monitoring can start.

EdgeConnect technology, powered by Hexagon's Xalt, is a cloud service which simplifies this process. It is integrated into GeoMoS Edge and enables secure cloud IoT connectivity between the field and the office. EdgeConnect uses a clever pairing procedure between GeoMoS Monitor and the router, making use of a standard, open HTTPS port, therefore requiring no additional IT modifications. Once paired, GeoMoS Monitor takes ownership of the device, making it impossible for the device to be hijacked, or for the data to be stolen. The user has full control of the device and can move it from one project to another. EdgeConnect removes the IT complexity from the monitoring installation equation, reduces costs and significantly shortens the time until monitoring can start.

3. CASE STUDY

The latest monitoring solution from Leica Geosystems described in Chapter 2 was released in November 2020, but it already has several success stories worldwide. For this article, the focus is on the monitoring system installed in the remote area of Iceland, to monitor slopes in the aftermath of landslides, which caused the evacuation of the whole town of Seyðisfjörður (Figure 7).

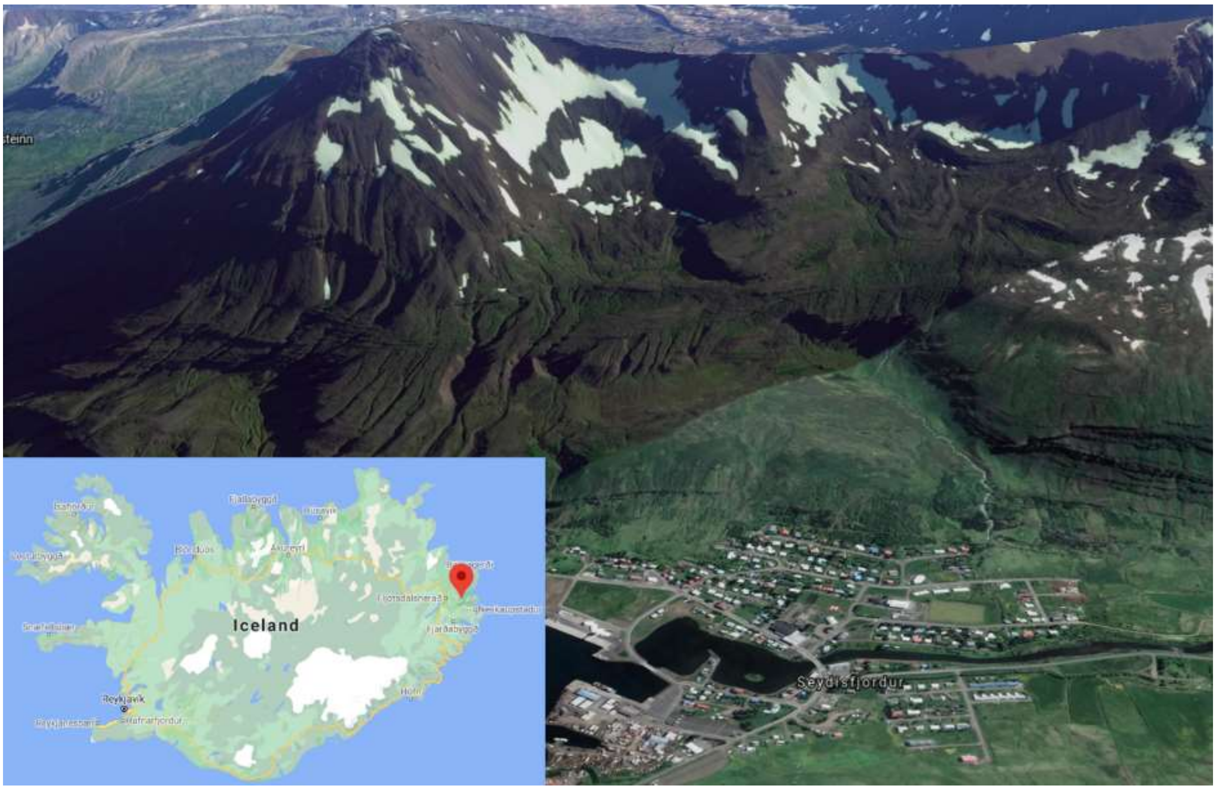

Figure 7 Location of Seyðisfjörður in Iceland (sources Google Maps and Google Earth)

3.1 Seyðisfjörður Landslides

Located in a narrow fjord in East Iceland, Seyðisfjörður is often lauded as one of Iceland's most picturesque towns. From 15th to 18th December 2020, several landslides hit this town, destroying or damaging more than 10 buildings (Figure 8), with the largest landslide on 18th December. The latest of which ranks as the most damaging landslide to have affected an urban area in Iceland. Ahead of the mudslides, intense rainfall had occurred in the area, with 569 mm of cumulative rainfall between 14th and 18th December – the heaviest rainfall measured over a five-day period in Iceland. In comparison, the average annual rainfall in Reykjavík is about 860 mm (URL1: Icelandic Met Office, IMO, 2020).

Figure 8 Damage caused by landslides in Seyðisfjörður (Photos: National Commissioner's Special Forces, URL1)

After the occurrence of landslides, the land continues to adjust for some time, causing further slope instability, especially during and after rainfall events. The December landslides produced several cracks on the slopes above the town and the IMO experts noted the importance of setting up measuring equipment for real-time monitoring of the slopes above the town.

3.2 Installed Monitoring System

Following the events, as an emergency measure, a manually observed prism and total station scheme was installed. In the early days of January 2021, automated monitoring equipment arrived at Reykjavík and the IMO surveying engineer travelled to Seyðisfjörður to install it. In total 34 prisms were mounted on the slope (2 reference points and 32 monitoring points) and the Leica TM60 I monitoring total station was set up in a stable area more than 1km away from the slope (Figure 9). The TM60 I – with imaging capabilities, together with a weather sensor, is connected to a Leica ComGate20 communication device with a SIM card from the local cellular provider.

Figure 9 Monitoring system in Seyðisfjörður. EF118 is the location of the total station, while green dots represent the prisms. Red lines depict the outlines of the December landslides.

To establish an internet connection between the router and GeoMoS Monitor installed at the IMO office in Reykjavík, following a simple code exchange the hardware was paired using EdgeConnect technology. Data visualisation and analysis is completed using GeoMoS Now! service, which is specifically designed to display monitoring data and is available on any mobile device or PC using a browser.

The installation of the monitoring system was quite challenging, due to the very few hours of daylight in Seyðisfjörður at that time of the year. The monitoring total station, its survey control and measurement arrays were commissioned and scheduled in GeoMoS Monitor within two hours, this mainly thanks to the AutoLearn feature, which automatically found and measured all 34 prisms in complete darkness. Without this technology, finding and learning the prisms would have needed to be bound to daylight and it would have been a much more time-consuming process, as each point would need to be located and measured individually. A weather sensor is measuring the environmental conditions in the vicinity of the total station, thus providing the valuable temperature and pressure information, both as meteorological corrections for total station measurements, as well as for providing weather data.

Figure 10 Leica TM60 I monitoring total station in the measurement hut

The monitoring measurement cycle consists of meteorological and prism measurements at 30min intervals. With the Leica TM60 I (Figure 10), being an imaging variant of the instrument, to provide added benefit, it automatically captures images of four defined image areas every hour during the daylight. This assists the IMO team to identify and visually confirm any changes in the locations between the prisms.

3.3 Data Analysis

For the purpose of this article IMO shared one month of their data, starting with the installation on 7th of January 2021. During that period, the communication device went offline eight times, if the changes of status during the configuration are ignored (Figure 11). This means that during the connection downtime caused by instability of the cellular network signal, GeoMoS Edge was collecting data autonomously and storing raw measurements locally on the communication device, fulfilling its design intent of "no data gaps", which would typically occur if there was no office to total station communication.

Figure 11 Changes of connection status in the period from January 7 to February 8

Raw measurements collected from the weather sensor are temperature and pressure, whereas the prism raw measurements are horizontal (Hz) and vertical (V) angle and raw slope distance. These locally stored measurements were automatically sent to GeoMoS Monitor (server) for processing immediately after the connection was restored. Figures 12 and 13 display the raw data availability during the same period. Final system configuration modifications were done on 15th January, which reduced the noise in total station raw measurements.

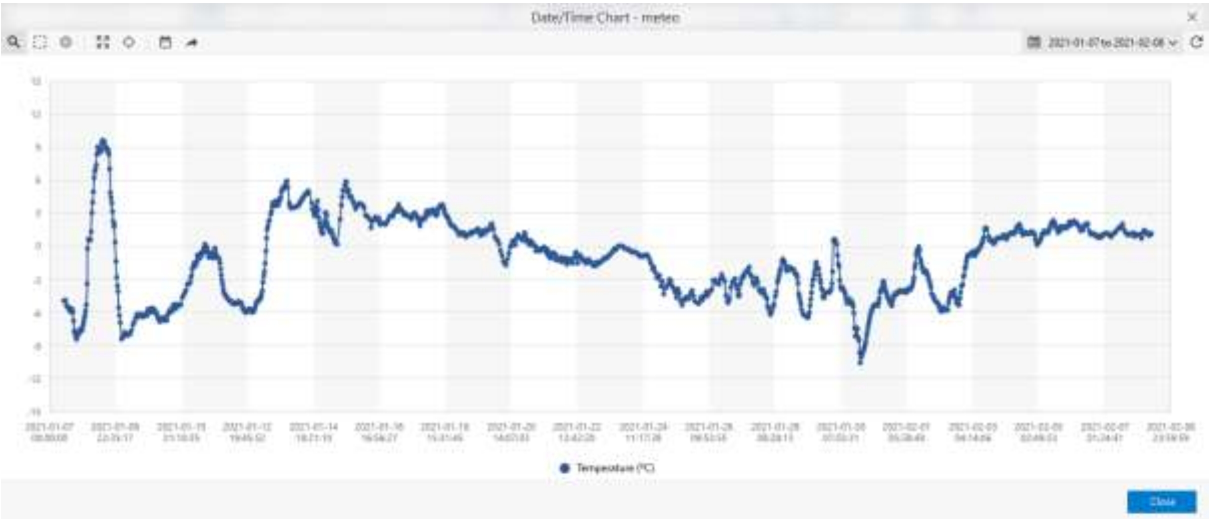

Figure 12 Temperature measurements from the weather sensor in the period from January 7 to February 8

The temperature measurements chart (Figure 12) is not displaying data gaps. The range within the temperature values were measured is between +9.7˚C and -10.6˚C. The prism measurements chart (Figure 13) for the points BF-02 and BF-19 shows occasional missing measurements, with the 48h period without measurements from midday 22nd to midday 24th of January 2021. However, success of electro-optical prism measurements highly depends on environmental conditions and requires a clear line of sight to the prism. If the line of sight is obstructed (snow, dirt on the prism or severely inclement weather), the measurement will fail. GeoMoS software has the intelligence with the option to retry the unsuccessful measurements, as well as measurements which do not fulfil the required quality, at the end of the cycle. This can increase the reliability in the system, although it is possible that the obstructed status has not changed.

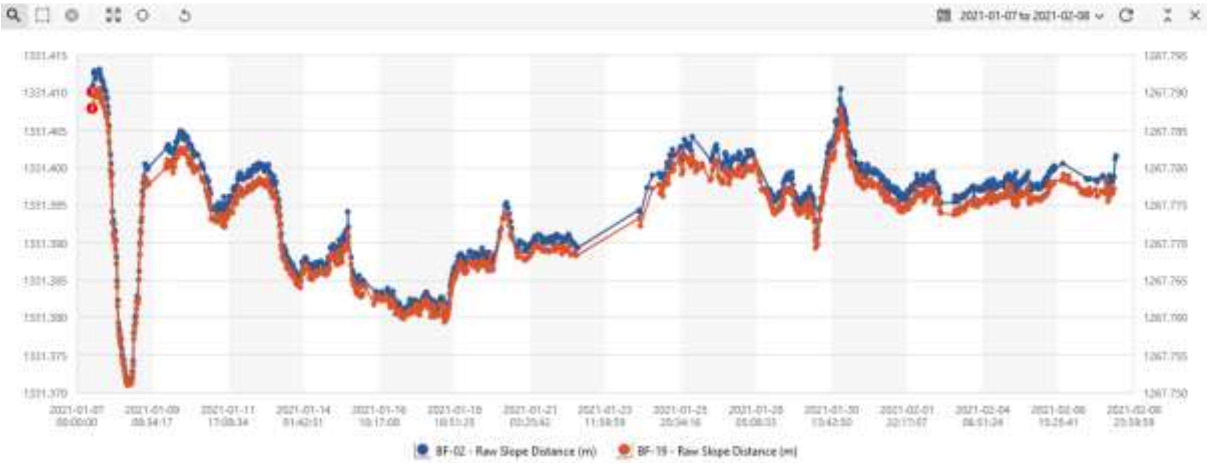

Figure 13 Slope distance measurements on BF-02, BF-19 points in the period from January 7 to February 8

As the TM60 is scheduled to take images during the daylight hours, that can also be utilised for environmental condition analysis. Figure 14 is showing the image captures of "StoraSkridan" image area before (22nd of January at 10:10AM), during (23rd of January at 13:43PM) and after (25th of January at 11:38AM) the period without measurements. From the images it is clear that there were severe weather conditions, in which measurements cannot be executed successfully. On the picture after that period, it is evident that the mountain is covered with more snow than before, but the air was clear and the total station measurements were successful.

Figure 14 Image captures from the TM60, showing the "StoraSkridan" image area before, during and after the blizzard

The World Weather webpage, which keeps weather data archive (URL2: World Weather) confirmed that there was a blizzard on the 23rd of January in Seyðisfjörður (Figure 15).

Figure 15 Weather in Seyðisfjörður on 23rd January 2021 (URL2: World Weather)

4 CONCLUSION

The purpose of every deformation monitoring system is to inform about the movements in the monitored area. When data is missing, people and objects in the vicinity could find themselves in danger, as the real-time notifications would not be triggered. Robustness and resilience of the highest quality monitoring solutions can be attributed to reliable edge computing technology. The ATRplus technology within the TM60 monitoring total station automatically adapts the measurement settings to current environmental conditions and ensures the targets are measured automatically up to 3,000 m away. GeoMoS Edge communicates with the total station and executes the measurement cycles, even when it is disconnected from the server. GeoMoS Edge recognises points which were not measured or were measured with insufficient quality and will remeasure them automatically at the end of the cycle. GeoMoS Monitor will receive the data which fulfils the defined quality thresholds, either in real-time or immediately after the connection to GeoMoS Edge is restored. EdgeConnect technology provides simple and secure communication between Edge and Monitor, whereas AutoLearn ensures the most timesaving and the only automatic target learning solution in the market.

Monitoring technology is continuously advancing and enables new solutions for the market. Developing robust monitoring sensors and adding intelligence both to hardware and software, enhances geodetic monitoring solutions, but there are measurement methodology constraints which still cannot be overcome. For electro-optical measurements with total stations, the constraint lies in its line of sight. Obstructions like unclean or snow-covered prisms, as well as severe weather conditions (fog or blizzard), can all cause failed measurements. The only solution for these impediments is adding different measurement methodology to the project, e.g. GNSS or geotechnical sensors. Monitoring sensors and software must cooperate and be able to adapt to any change in the environment to achieve the ultimate goal of preventing data loss. Only when data is available, the hazard of the monitored object can be ascertained.

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BIOGRAPHICAL NOTES

Dr. Lidija ŠPIRANEC is a Senior Product Engineer in the Monitoring Product Management group at Leica Geosystems. She received her Ph.D. in geodesy and geoinformatics from Faculty of Geodesy at the University of Zagreb, Croatia.

Mr. Elias NIEL is a Product Engineer in the TPS Product Management group at Leica Geosystems. He received his M.Sc. degree in Surveying and Geoinformation from the Vienna University of Technology, Austria.

CONTACTS

Dr. Lidija Špiranec
Leica Geosystems AG
Heinrich-Wild-Strasse
Heerbrugg
SWITZERLAND
Tel. +41 71 727 3459
Email: lidija.spiranec@leica-geosystems.com
Web site: https://leica-geosystems.com/

Mr. Elias Niel
Leica Geosystems AG
Heinrich-Wild-Strasse
Heerbrugg

SWITZERLAND
Tel. +41 71 727 4758
Email: elias.niel@leica-geosystems.com
Web site: https://leica-geosystems.com/