Development and implementation of a sensor-supported rock bolt system for underground monitoring

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ABSTRACT: Alongside with digitalization in underground mining and tunnel construction, user-friendly acquisition and processing of data is of paramount importance, considering the particularities of the working environment. Various conventional data measurement systems are currently in use for different applications; however, their scope is somehow isolated and not applied for a large-scale basis monitoring of default ground support systems such as rock bolts. For underground applications, system sourcing, and installation of special monitoring bolts is cost intensive and impracticable for a large-scale application. A low-cost intelligent rock bolt assembly concept was developed during the EU-funded illuMINEation project, part of the horizon 2020 research and innovation program. This low-cost intelligent rock bolt assembly allows an easy application with already installed rock bolts, or in combination with rock bolts featuring an integrated tendon sensor. The principal idea is to provide real-time recordings and visualization of geotechnical and environmental measurands on a large-scale collective basis.

Keywords: ground support, rock bolt, monitoring, tendon sensor, illuMINEation.

1 INTRODUCTION

Rock bolts (or simply bolts) are used for ground support in underground excavation, they are classified as rock reinforcement system. The working principle of rock bolts is based on load transfer from a bolt tendon to the ground. Main system components of a typical rock bolt system are tendon and bolt head (plate and nut). For the present use case, a mechanically anchored rock bolt was used, which features an expansion shell for end-anchorage based load transmission.

To be able to record geotechnical and environmental measurands in an underground working environment, various data measurement systems are currently in use. Examples are either sensor boxes installed in underground openings, or special instrumentation bolts. Those systems feature several disadvantages, such as high costs associated with material and installation. Also, non-standard items (bolts) are used to compare the performance of default rock bolts used for ground support purposes. From 2019 to 2023, a low-cost intelligent rock bolt assembly was developed in the course of the illuMINEation H2020 project, which should overcome before-mentioned disadvantages of conventional underground measurement systems.

2 INTELLIGENT ROCK BOLT ASSEMBLY

From an early conceptual stage on, an attempt was made to develop an intelligent rock bolt assembly based on default rock bolt systems which are currently in use in underground excavation. The idea was to collect data at two different points: along the tendon (geotechnical sensors) and in the area of the bolt head (environmental sensors). Figure 1 shows the principal layout of the intelligent rock bolt assembly with a low-cost sensor bolt head.

Figure 1. low-cost intelligent rock bolt assembly.

Sensor bolt heads (add-on nuts) of the first and second trial generation comprise of a 3D-printed casing, various sensors (see 3.2), a microprocessor, a rechargeable battery pack (3,7 [V]), a LoRa transmitter, and an antenna. Due to energy consumption restrictions, a low-range (Lo-Ra) Wi-Fi protocol was chosen. Add-on nuts are installed onto default bolt tendons in the protrusion area, and feature a QR code, as well as an optional LED status indicator. To be able to incorporate sensors with a higher energy consumption and a signal repeater function, sensor bolt heads are also available with a 110-230 [V] main power supply feature. Figure 2 shows examples of low-cost sensor bolt heads.

The principle of the tendon sensor, originally developed by Montanuniversitaet Leoben (WO/2020/169356, Noeger et al. 2021) is based on ink printing technology. A printed-on low-cost resistance-based sensor allows monitoring of the strain in the tendon, and thereby the bolt load (utilization rate). The tendon sensor is equipped with a data readout interface to the sensor bolt head.

Figure 2. sensor bolt heads (red casing battery powered version, blue casing mains power supply version).

3 USE CASE TEST INSTALLATION

3.1 RHIM Breitenau underground mine

A series of installation tests of intelligent bolt heads were conducted at the RHI Magnesita's Breitenau underground mine, in Austria. The Breitenau magnesite mine is typical for alpine mineral deposits and highlights the complex geological and mining situation encountered in the alps. The magnesite deposit Breitenau represents the largest known sparry magnesite deposit in the eastern alpine region. Mining takes place at a significant depth, with 1000m of overburden in the lowest mining section. This is one of the biggest challenges encountered in this underground mine, mainly concerning geotechnics and transport logistics (Drnek & Froemmer, 2008)

The room and pillar mining method (with backfill) used in the upper mining levels is associated with roof fall risks and pillar stability issues as well as the requirement of large numbers of support measures. Rock bolts are the main ground support used at Breitenau underground mine, with about one rock bolt per square meter installed in the roof and side walls. In room and pillar mining, the mineral extraction is undertaken in slices in upward direction. This implies that after each slice, all rock bolts are blasted and replaced again, resulting in about 10 000 rock bolts being installed every year. In the lower areas of the mine, an open stoping mining method (with backfill) is being used and it is associated with long development and ore drifts that must maintain stable and safe for a longer period of time. Therefore rock bolts are installed to maintain the stability of the underground mine.

In the areas where the high stresses are present, continuous acquisition of the information on the rock mass movements and stress changes is of paramount importance. Thus, it is possible to react accordingly and on time if potential risks occur. The intelligent rock bolt system would be installed in high stress areas in addition to the existing rock bolts with the aim of making the mine and working environment safer using the so called "safe zone concept".

3.2 Test installation program

The test installation program in Breitenau mine comprises of three development and test phases. The first two stages are linked to the tests of the mock-up intelligent bolt heads for environmental measurements. The third stage is the final testing phase, with the objective to install a complete system (see Figure 1) including the tendon sensor for geotechnical measurements.

Based on sensor availability and energy consumption, the following sensor portfolio was defined for an initial testing series (stage 1 and 2):

- Battery-powered sensor bolt heads (red version): air temperature, air humidity, air pressure, and inclination/declination (positioning).
- Mains power supply sensor bolt heads (blue version): air quality, noise, and repeater function.

The first trial stage involved the installation of ten battery powered sensor bolt heads and a LoRaWan gateway. Figure 3 shows the mounting of add-on nuts onto previously installed rock bolts. Installation turned out successful, initial measurements were recorded and evaluated. From the first trial stage, the following findings for further decisive improvements were observed and later notably ameliorated:

- Handling and practicability – different installed bolt types with different outer diameters did provide an initial challenge.
- Limited signal range – underground environment.
- Too short battery lifetime – processor configuration.
- Brittle casing – harsh mining environment.

With stage one successfully completed, consecutive tests (stage two) in Breitenau mine focused on the blue sensor bolt head version of the intelligent bolt heads, as well as the real-time visualization (see consecutive section). They act as a transmitter of the LoRa Wi-Fi signal, giving the possibility to extend the existing Wi-Fi network in other working areas of the mine without additional gateway installation. Moreover, blue nuts are connected to the mains power supply allowing the installation of high-energy consuming sensors such as gas emission measuring sensors. The idea is to track down emissions of toxic gases such as CO and CO_2 and indicate if the threshold values are being exceeded. Such a system could minimize the need for daily measurements done manually by mining personnel. Most important, it would detect if high emissions of CO_2 and CO are present, indicating potential fire hazards or risks for the mine personnel. For the remaining year of 2023, further intelligent sensor bolt heads will be installed in the course of stage three test installations, with the aim of gathering data over a longer time period and implementing such a system on a large scale.

Figure 3. underground installation red type sensor bolt head, Breitenau mine, horizon X.

4 DATA PROCESSING AND VISUALIZATION

The current data transfer in the Breitenau mine works as follows. Red or blue sensor bolt heads are connected to the one LoRaWan gateway installed at horizon X, which is connected to the online application server (interface with IIoT – industrial internet of things). For future applications, blue sensor bolt heads might alternatively communicate directly with the application server avoiding additional gateway installations (see Figure 4).

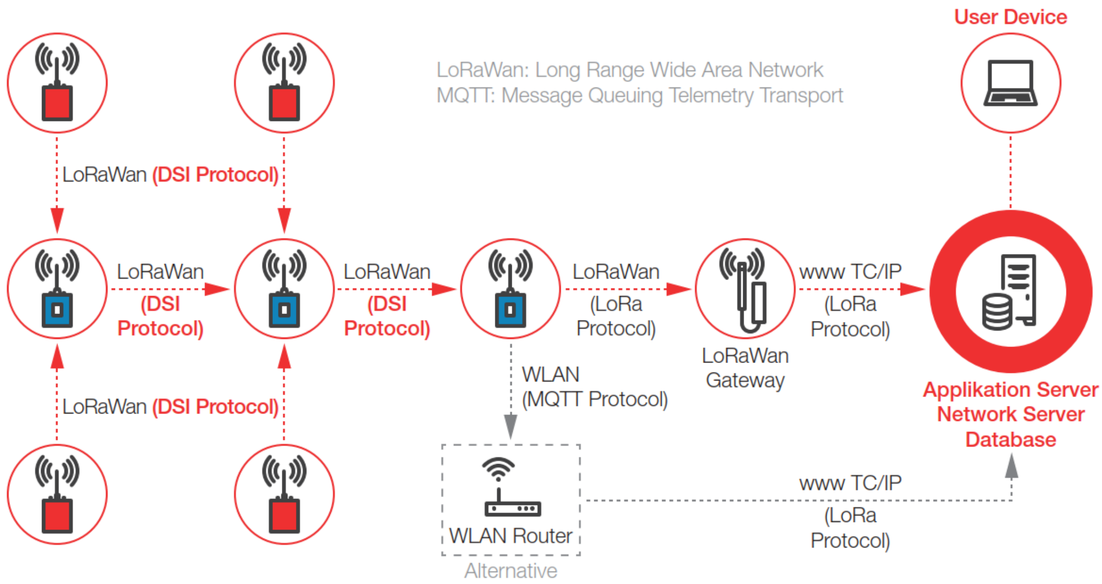

Figure 4. data processing scheme.

Figure 5 shows the digital twin of horizon X, including a 3D point cloud, the location of each intelligent bolt head with an identification number, and real-time data readings from sensors.

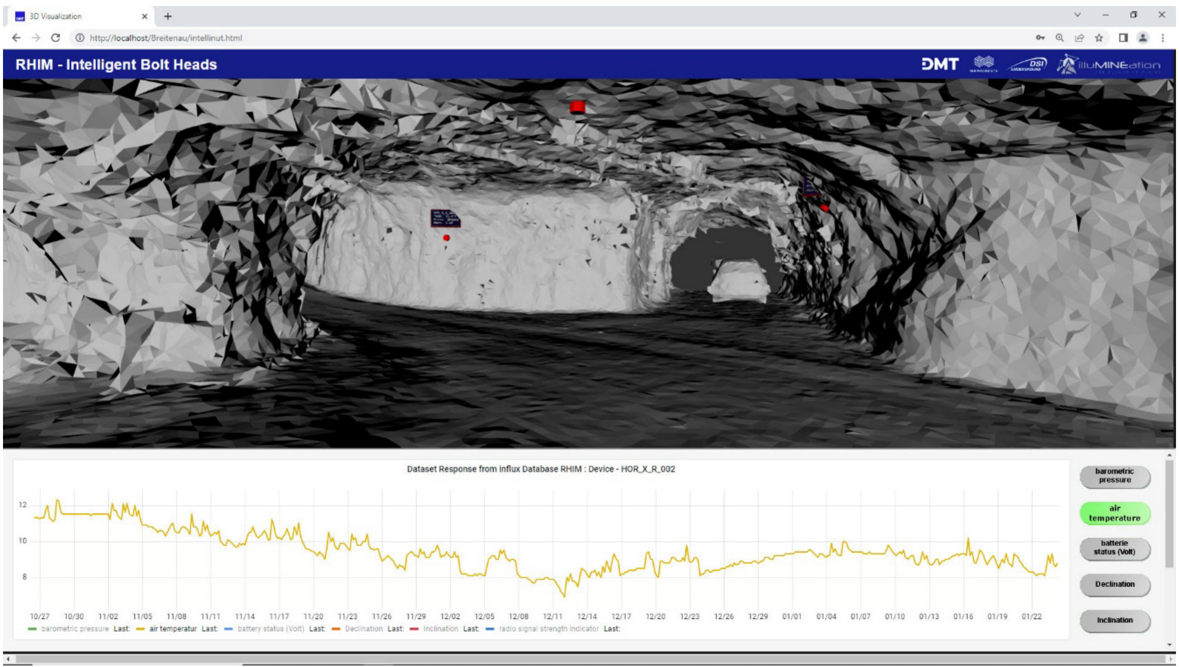

Figure 5. digital mine twin horizon X – exemplary real-time visualization.

Data visualization of gathered data from the intelligent bolt heads was displayed via a Grafana online dashboard. Grafana is an open-source interactive data visualization platform that allows users to see their data via charts and graphs that are unified into one or multiple dashboards. In the scope of the illuMINEation project, the originally developed Grafana platform for Breitenau use case was modified (HTML elements and X3D objects) and integrated with the official IlluMINEation IIoT platform. In order to have better visualization of where each intelligent bolt head is installed, a 3D interactive map from LiDAR point cloud was integrated.

Due to the current Wi-fi network infrastructure limitations, all the tests were conducted around one location in the mine (horizon X) where the access point and gateway are installed. During 2023, it is planned to extend the current network infrastructure towards lower areas of the mine which will allow more testing locations.

5 SUMMARY AND CONCLUSIONS

Although it was a first-time application, the technology readiness level (TRL) of the developed system was already in the range of 5-6. Testing of tendon (geotechnical) sensors of the sensor-supported rock bolt system is of paramount importance, hence the technology must yet be tested and proven. Limitations with regards to available Wi-Fi network infrastructure and mains power supply, as well as the LoRaWan signal range in underground openings must be overcome in the course of future applications.

Further tests involving a larger number of intelligent sensor bolt heads are required, in order to compare the data coming from the sensors with the one measured by conventional devices. In case there would be no significant variations and deviations, the system could be used for daily ventilation checks. The field of application can also be extended by implementing different sensors for different purposes for particular use cases (underground mines). Application of blue sensor bolt heads with repeater function could be very helpful for the extension of the range in the working areas without the need of installing access points and gateways.

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