GUARD - SMART FLEXIBLE PROTECTION SYSTEMS AGAINST NATURAL HAZARDS

Vjekoslav Budimir[1], Helene Lanter[2], Sascha Schultes[2]
[1] Geobrugg AG Representative Office Croatia, Zagreb, Croatia
[2] Geobrugg AG, Romanshorn, Switzerland

Abstract

Flexible steel protection systems against natural hazards are difficult to access in mountainous areas and inherently become difficult to monitor and maintain over the years. Many small-scale events, such as rock-fall below the service energy limit (SEL) defined by the EAD 340059-00-0106 or debris flows under the maximum impact pressure of the net, acc. to EAD 340020-00-0106, go unnoticed, but the repetition of several events into a protection system still needs regular maintenance to guarantee full performance in case the design event occurs. Furthermore, experience has shown that the corrosion can vary strongly in small localised areas and lead to unpleasant surprises. Therefore, the understanding of microclimates favorable to the corrosion process needs to improve. A newly developed IoT device, called GUARD, was developed aiming to provide monitoring of flexible steel protection systems. It is equipped, amongst others, with a rope force sensor and an accelerometer. The second target of the device is to pass from repair and pre-ventive maintenance to the concept of predictive maintenance by evaluating the local corrosivity and the associated lifetime of the protection system with a specially developed corrosion sensor. These sensors have been deployed over the past years on 40 sites in 13 countries in Europe. Even many flexible protection barriers are equipped with GUARD in North America, Hawaii, Australia and New Zealand. This contribution aims to highlight the monitoring with the GUARD and the inspection concept that can be developed from it, with a highlight on the data collected so far.

Keywords: IoT device, flexible protection system, GUARD, predictive maintenance

1 Introduction

According to the definition of the Internet of Things (IoT), it should automatically link relevant information from our environment and make it available in the network, it is shown in Figure 2. The increased need for information comes from the fact that we increasingly want to know about the status of things, some of which were previously difficult to obtain, but which are essential. This condition information consists, for example, of data on the current use, aging or environmental conditions of the object and is intended to improve usability, such as early recognition of the need for maintenance, the replacement of elements or the improvement of the environment. This paper aims to illustrate the purpose of IoT in the field of infrastructure protection against natural hazards by means of flexible protection solutions. These protection solutions represent the object about which it is necessary to generate status information. Until now, the condition has been determined by periodic inspections, sometimes laborious or dangerous manual work. Often, certain protective measures were also forgotten over time, resulting in a renewed threat to the transport infrastructure if this protective solution is not maintained.

DOI: https://doi.org/10.5592/CO/CETRA.2022.1493

The condition information that is of primary interest is, on the one hand, the “filling condition” of a protection solution. Can it still provide the necessary protection if it is two-thirds full? On the other hand, its aging process. Corrosion attacks the steel and the stability decreases over time.
By using IoT technology, when this condition information is collected, on the one hand, the planning of maintenance work can be planned efficiently and it is no longer necessary to move into a dangerous area on the off chance for the purpose of periodic examinations, and on the other hand, the aging process can be monitored and a possible replacement of a protection solution after several decades can be planned into the budget at an early stage.
The expansion of settlements, the melting of permafrost or frequent heavy rainfall events are a few examples that require protection against rockfall and debris flows in more and more places. In the last 30 years, rockfall barriers made of steel wire nets have become established world-wide as a protective solution. Parallel to the flexible rockfall barriers, flexible debris flow barriers have been developed and installed worldwide, as well as avalanche barriers made of mesh in the fracture area.

1.1 Problem definition

One aspect of the transport infrastructure is its condition monitoring in more or less real time in order to carry out or plan targeted maintenance. Protection against natural hazards is another aspect that significantly influences the operation and maintenance of the infrastructure. There are various protective solutions to stop natural hazards, for example, flexible protective fences made of steel mesh. These are installed at the edge of the infrastructure and should be maintained regularly.
Protective structures are mostly built in the mountains or on the sea coasts. The systems are usually located in rough terrain; they are difficult to reach and visual monitoring is often not possible. The control and maintenance of such systems have been neglected in many places in recent decades. Some of these solutions have also been forgotten, mostly hidden by growing vegetation. However, this poses a considerable danger if, for example, a rockfall fence slowly fills up and is not cleared. If the largest possible rockfall, for which the fence was designed, should then occur, the energy absorption capacity is not guaranteed in such a case.
Another scenario outside of impacts from falling rocks or a debris flow, for example, is the slow but safe degradation of corrosion protection exposed to the environment. Different corrosion classes are standardised and determine the expected service life. Depending on the location and local conditions (e.g. frequent scattering of salt on the road), the corrosion class can be over or underestimated, leading to over-dimensioning of the protection solution or, in turn, to early maintenance measures or even replacement of a protection solution that was not yet included in the budget planning.
Maintenance is event and location-dependent. In practice, those responsible usually define intervals for the on-site inspection of the barriers. This can mean one to several times a year. But even with frequent checks, an event can remain undetected for a long time. If then an event, for example a major rockfall, reduces the protective capacity, or the corrosion of certain elements, there is subsequently an unnecessary safety risk.
In order to better document the inventory of flexible protection solutions, monitor them in real-time and plan maintenance work in advance, a multifunctional IoT sensor called GUARD has been developed, see Figure 1. After a detailed presentation of the device, additional application examples will be shown.

2 IoT device Geobrugg

A device was developed that measures the environmental conditions, i.e. humidity, temperature, corrosion process, as well as dynamic and quasi-static load by means of the acceleration sensor and force measurement in the rope.

2.1 Development of an IoT device according to the IoT definition [1]

Depending on the application, it must be possible to retrieve the information on the physical device by means of RFID or QR code. This is the case with this device, in that RFID makes it possible to upload updates to the device, as well as a QR code, which makes it possible to directly record all relevant information via a web app during installation, or to display it in the data platform. On the other hand, it is also required that the information that is transmitted can be edited. In this case, the requirements are relatively high, the hardware must be reliable, have a low maintenance effort (since a high failure rate requires maintenance work on a large number of devices that are sometimes far apart or difficult to reach), and have a low energy consumption. Finally, the acquisition costs should be relatively low, since as many physical locations as possible need to be equipped. The developed GUARD fulfilling all these requirements. It has a low energy consumption, the measured data are sent at least weekly or immediately in case of extraordinary events, and the device is equipped with a battery that has a life span of about 7 to 10 years, depending on where it is exposed (warm/cold, good/bad network connection).

Figure 1 GUARD Hardware development over the last few years

The data is transmitted via the mobile network (GSM/UMTS/LTE) and displayed in a login-protected data platform. There, the transmitted data can be evaluated and interpreted and the warning process can be defined.

2.2 Sensors in the Guard

The specially developed sensor technology measures the corrosion process taking place, is equipped with temperature and humidity sensors, is equipped with acceleration sensors that can report a dynamic process and also measures the force in the support cables of the protective solution in order to perceive slow, pseudo-static changes in the system. The data is transmitted directly to a cloud via the mobile network (GSM, UMTS or LTE). An online platform allows the viewing of the processes taking place in quasi real-time (see Figure 1). Responsible persons thus know the status of their barrier not only directly after an on-site inspection, but continuously.

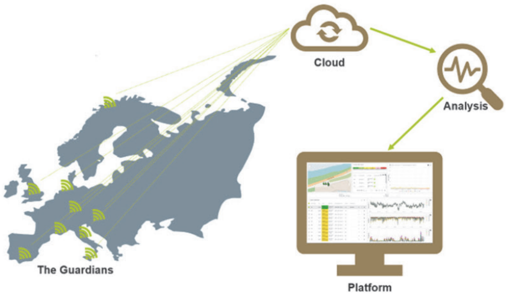

Figure 2 Functional principle of the data transmission of the guards and the anecdotes of their data

Table 1 The sensor technology and technical specifications

Rope force measurement	up to 30, 000 kg
Acceleration	0 g to 200 g
Orientation	XYZ axis
Corrosion	Current (μA)
Temperature	- 50 °C to 80 °C
Humidity	0 % - 100 %
Energy	Battery voltage (V); running time 7 to 10 years
Signal strength	RSSI

2.3 Dynamic load cases

The dynamic load cases, such as a rock fall, a debris flow or tree fall during a storm or forestry work, are detected and measured by means of two acceleration sensors. The two sensors measure two ranges between 0 to 15g and 0 to 200g. In the long term, the data collected should enable a statement to be made about the possible location of an impact, as a rockfall protection structure can be several 100m long, as well as an estimate of the size of the stone or the volume of a mudflow. Here, the collection and interpretation of data at several locations is elementary. Algorithms can be developed from this database in the future.

2.4 Static load cases

Static load cases, such as slowly increasing snow cover, load of filled material after a debris flow, etc, are determined by means of a rope force measurement. Therefore, the GUARD is mounted on one of the supporting ropes or restraining ropes of the shoring, see Figure 3. Thanks to a minimal deflection of the rope under the GUARD, the force of the rope can be deter-mined via strain gauges.

Figure 3 Guiding the rope along the Guard and the wire rope clamp, allows measurement of the force in the rope

2.5 Corrosion

Besides dynamic, gravitational natural events, corrosion is the most important factor for a reduced service life of plants [2]. Worldwide field experience has shown that the corrosion classes according to EN ISO 12944-2 [3] vary greatly in a small space and can lead to unpleasant surprises. Therefore, the understanding of microclimates favouring corrosion needs to be improved. One aim of the GUARD is to enable the transition from repair and preventive maintenance to predictive maintenance by assessing local corrosivity. Among other things, this device is equipped with a specially developed corrosion sensor. The corrosion sensor constantly monitors the environmental conditions of the barrier and allows a statement to be made about the service life of an installed flexible protection system, leading to the concept of predictive maintenance.
Corrosion is problematic in the field of natural hazard protection because the functionality of protection systems depends on the full integrity of their components. An adequate description of the corrosiveness of the future site of a steel protection system is fundamental to ensure the correct corrosion protection on the steel components. Nowadays, the corrosiveness of the environment is defined according to EN ISO 12944-2 and described in 6 different corrosion classes from C1 to CX. This environmental definition leaves much room for interpretation. The lifetime prediction of wire zinc coatings according to ISO 9223:2012-05 [4], for example, is always inaccurate by at least a factor of two according to EN ISO 12944-2. Where, simply put, C1 is unproblematic for a Zn-Al coating, which, on the other hand, quickly disappears in a C5 environment. Unfortunately, these classes are very general and based only on regional climatic aspects. The corrosion process is more complex and depends on several factors that can vary greatly locally. Factors that create a microclimate that differs from the corrosivity classification based on regional climate are, for example, an industrial plant that emits polluted air, the presence of local water rich in chloride or sulfur, areas that are always in the shade and therefore wetter, or, on the other hand, very dry areas with some salt input that is not regularly washed off. The de-icing of roads in winter also induces a microclimate along the first meter above the road, which leads to accelerated corrosion due to the salt input, although in an alpine environment one would think that the corrosivity class must be C2. The need to develop a special corrosion sensor seemed to be of utmost interest to define and monitor such microclimatic areas around protection systems.
The predicted lifespan of a protective structure, for example, can be between 30 and 90 years according to the defined climate and standard. Without ongoing measurements, the lowest value must be assumed, which can cause unnecessary costs and is also not convincing in terms of sustainability. With ongoing measurements, the infrastructure manager knows the real corrosion and can act accordingly. The corrosion sensor was tested in a climate chamber and on various test sites.

The results in the climate chamber and the results on the test sites seem to indicate a proportionality between the measured current and the weight loss on the corrosion sensor. Over 200 sensors have been used so far and initial results seem to confirm the trend. Further conclusions can only be drawn if the devices are used outdoors for a longer period of time.

2.6 Remaining sensors and displaying the data

The remaining sensors, such as temperature and humidity, as well as the voltage of the battery and the signal strength of the mobile network, allow a plausibility check (do the temperatures correspond to the environment) and a status display of the respective device in order to be able to carry out any maintenance on the device itself at an early stage. The data is clearly displayed on the online platform and provides a variety of decisive information on the current condition of the protection solution, Figure 4. The calculated removal rates of the corrosion sensor are also displayed, as well as the converted deflection of the rope as a force in Newton.

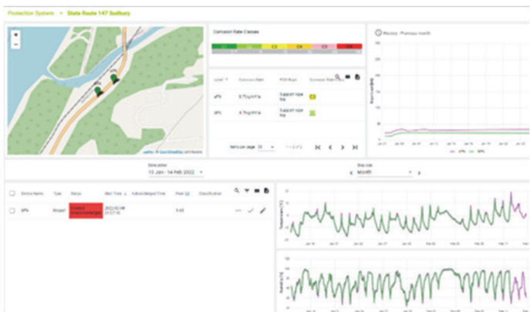

Figure 4 Example: Overview of shoring on the platform

3 Application example with dynamic impacts

First Guards were installed at several rockfall and debris flow barriers across Europe in summer 2019. The locations were selected based on known frequent impacts and highly corrosive areas. A rockfall protection net protecting a road was equipped with three guards (see Figure 5).

Figure 5 Guard mounted on the support cable of a rock-fall protection structure

As can be seen in the pictures, this shoring is a typical example, which, despite its proximity to the protective infrastructure, is increasingly dis-appearing under the growing vegetation and is slowly being filled with small debris and foliage (see Figure 6 and 7).

Figure 6 Rockfall protection barrier disappearing into the vegetation

Figure 7 Barrier filled in over time

On 16 June 2020, a small rockfall occurred. It was a boulder with edge lengths of about 100 cm x 100 cm x 40 cm and a mass of about 1, 000 kg. A GUARD installed in the field adjacent to the impact recorded the rockfall event: Acceleration 14 , 7 g, at 18:00:32 (see Figure 8 and 9). The event immediately triggered an SMS and e-mail message about the impact via the platform. This enables those responsible for maintenance to take appropriate measures.

Figure 8 Impact on 16 June 2020

Figure 9 Absolute acceleration of rockfall on 16.06.2020

On 4 March 2021, another dynamic impact triggered a report, this time it was a piece of a tree trunk during forestry work (see Figure 10 and 11).

Figure 10 Cutting of a tree trunk after clearing and grubbing of vegetation around the construction

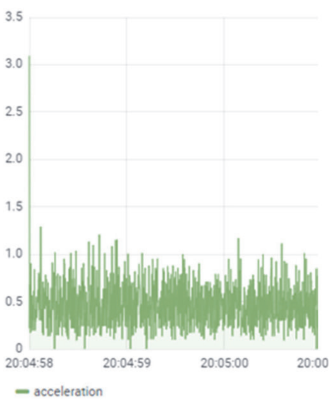

Figure 11 Absolute acceleration on 04.03.2021 due to the tree trunk impact

4 Collecting data worldwide

These sensors have been deployed over the past years on 40 sites in 13 countries in Europe (see Figure 12). Even many of flexible protection barriers are equipped with GUARD in North America, Hawaii, Australia and New Zealand. The aim is to use the information to improve the evaluation by developing algorithms to automate data interpretation. The data will also provide the basis for planning more needs-based inspections and making lifetime estimations more accurate in the future.

Figure 12 Platform print-screen with an overview of worldwide sensors

5 Conclusion

This article on the GUARD shows the development of an IoT device for monitoring shoring against natural hazards to protect infrastructure. The GUARD can be installed in a few minutes - on systems from a wide range of manufacturers. With its independent power supply, it works for up to ten years without on-site device maintenance. The GUARD provides the most important information to ensure that protective measures function reliably. It has been tested under a wide range of conditions at various locations in Europe.

This IoT solution should make it possible to carry out fewer inspections or inspections on demand and still ensure 24/7 monitoring. This reduces the inspection costs of the shoring and increases the safety level for the workers in the danger zone and the shoring itself. Preventive maintenance is also possible. Over time, events are logged and important conclusions can be drawn by combining data, e.g. wildlife (rockfall), weather data (debris flow) and air pollution (corrosion). This monitoring solution makes it possible to achieve smart infrastructures of existing and new buildings in the field of natural hazard prevention.

References

[1] Internet of Things, Wikipedia, Wikimedia Foundation, 26.04.2021., en.wikipedia.org/wiki/Internet_of_things.

[2] Hofmann, H., Hörtnagl, A., Sorg, M., von Wartburg, J.: Development of a digital de-vice for monitoring and predictive maintenance of flexible steel protection systems against natural hazards, 14th Congress Interpraevent 2020.

[3] ISO 9223:2012-05 Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation

[4] Corrosion protection of steel by coatings and coatings 4, DIN EN ISO 12944-1 to DIN EN ISO 12944-8, 1998 Beuth