Monitoring of the entrance slope to tunnel 40 of the Palencia - La Coruña line (ppkk 277+100 - 277+457)

Context

Slopes can be susceptible to problems associated with instabilities that pose a geological risk to railway infrastructure. ADIF promotes a predictive maintenance approach to this type of problems in unstable slopes through the implementation of ecological, digital and safe solutions for the railway sector.

This case study deals with a slope in northwestern Spain located at the entrance of a tunnel. This area has a high frequency of rainfall and also has the presence of a reservoir with continuous rising and falling of the water level, which exacerbates the instability of the slope that consequently can cause problems in the infrastructure.

Solution

ADIF deployed a data acquisition network based on IoT Worldsensing technology, capable of autonomously and reliably capturing data at remote measurement points using telematics-enabled dataloggers with no need for external connectivity and low power consumption.

The sensor network consists of a weather station and wireless clinometers, responsible for measuring displacements, slopes, temperatures, rainfall and relative humidity.

Specifically, the slope monitoring system under study is composed of the following elements:

- Wireless clinometers

Clinometers, alone or in close clusters, act as a local datalogger, measuring, recording and sending data to a gateway that acts as a central datalogger or hub.

The project is supported by the Europe's Rail Joint Undertaking and its members.

Image 2. Installation of clinometer on a mast embedded in the ground.

Image 3. Clinometer orientation

The clinometers are distributed over the entire surface of the slope and can be installed on the ground as well as on rock or concrete. On this occasion, 4 clinometers have been installed on the sleeper, 3 clinometers on rock, 2 clinometers on the concrete wall or tunnel gable and 7 clinometers on the ground.

- Gateway

It is in charge of capturing the signals delivered by the sensors in the local network. It is the device from which the entire system is controlled at the level of communications with the outside, being these communications by radio using the LoRa (Long Range) protocol, a low power consumption wireless network. The gateway has been powered by a solar panel.

- Weather station

The system is completed by a meteorological station capable of simultaneously reading rainfall, ambient temperature and relative humidity. Its purpose is to monitor rainfall in the study area, as it critically affects the hydrology and geotechnics and, therefore, the slope stability conditions and the properties of the soil itself.

In addition, the solution is completed with a study using satellite SAR interferometry technology with satellite radar images from the European Union's Copernicus Program. This study makes it possible to analyse the historical deformations produced in the tunnel slope, as well as to indicate the points of greatest reflectivity for the location of the sensors and, thus, to design the slope instrumentation more efficiently.

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Results

The clinometers installed can withstand the harsh weather conditions in the long term, requiring zero maintenance once installed for a battery life of up to 15 years. In addition, those devices installed on the track correspond to a specific version of the device compatible with normal railway operation: high resistance to vibrations and internal antenna, to avoid any protrusion protruding from the cover of the device.

These sensors allow on-site and real-time data collection of:

a) Movement and inclination control on the slope and railway platform.

b) Meteorological information relevant information related to the behaviour of the slope and its evolution.

c) Correlation of environmental variables with the measurements obtained (Image 5).

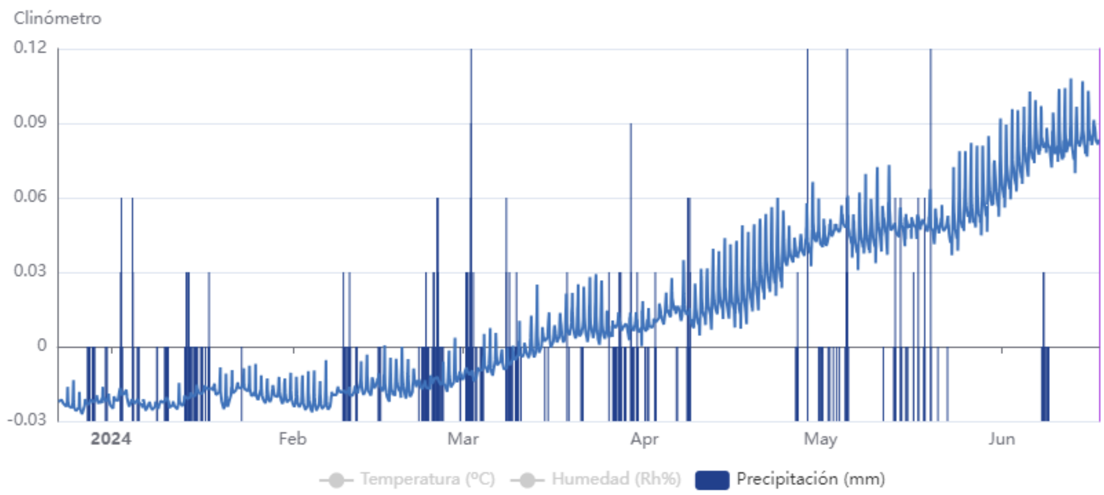

Image 5. Clinometer measurements and real-time precipitation data.

Continuous monitoring allows the performance of different analyses based on statistical algorithms and artificial intelligence. In this sense, the following flow chart (Image 6) shows the main steps involved in data analysis, as well as the alarm system to be used.

The first step in the data analysis is the elimination of the environmental effects that directly influence the measurements obtained. In this sense, the Linear Regression Model (MLR) is used to eliminate fluctuations due to changes in environmental conditions. The variable defined as predictor is temperature, which shows a high correlation with the measurements obtained. This analysis makes it possible to obtain, for each sensor, a Hotelling T2 control chart in which the trend of the data is studied statistically. The Hotelling T2 control chart is a multivariate tool used to monitor processes and detect significant changes in the variables of interest. In Hotelling's T2 chart, T2 values are calculated for each observation, and these are compared to an upper control limit. If a T2 value exceeds this limit, a possible anomaly in the process is indicated. This method is particularly useful in situations where variables are correlated, as in the case of clinometer measurements.

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The use of artificial intelligence is becoming more and more common. In this way, a neural network of recurrent type (LSTM, Long Short-Term Memory) has been implemented with the objective of predicting measurements in the next two days, considering precipitation as an extreme variable, since precipitation has a great impact on the values obtained from the clinometers, probably due to soil saturation and other factors related to humidity and earth movement. By including precipitation as an extreme variable in the model, the LSTM network can make more accurate and reliable predictions about future measurements.

After these analyses, several alarm systems have been implemented, considering a training period in which the study slope is considered undamaged. This alarm system is implemented in real time, which allows advance warning of any anomaly.

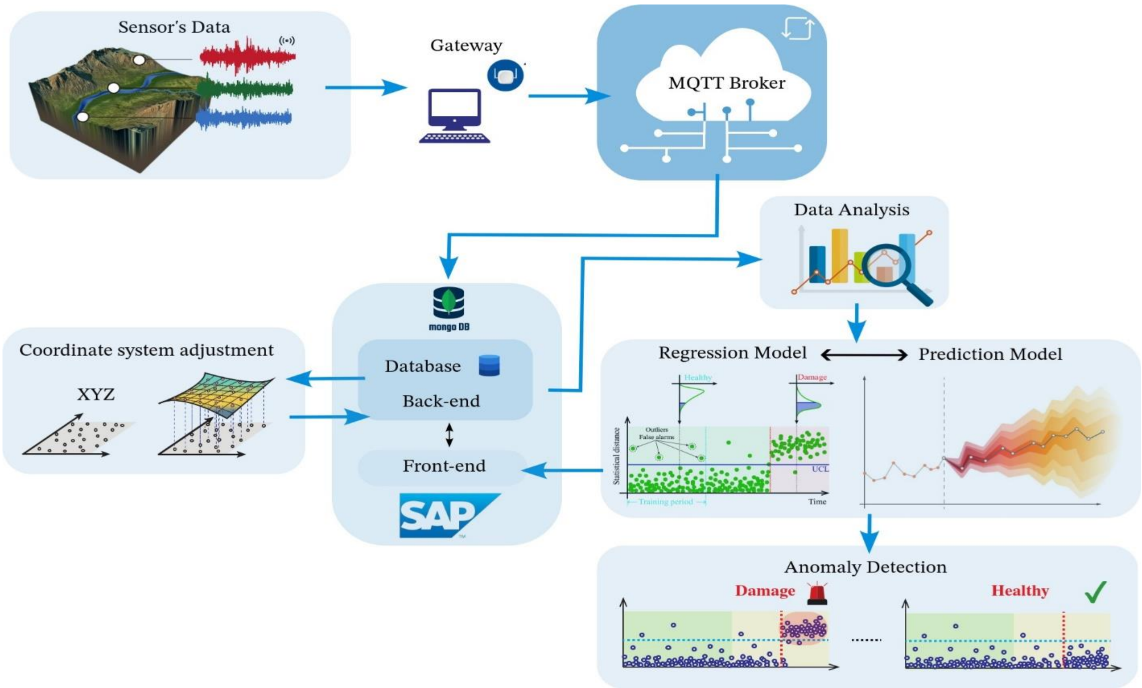

Image 6. Flow diagram of the analysis of the behaviour of clinometers in Palencia - La Coruña.

Benefits

Wireless sensors, which are installed on the surface, within the unstable slope under study, can measure the surface deformation of the slope, which allows the interpretation of failure mechanisms or precursors of movement.

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Image 7. Clinometer installed on a rock.

These systems allow a higher sampling frequency, and increase the adaptability, reliability and cost-effectiveness of predictive monitoring of slope instabilities and potential landslides that could affect infrastructures.

In its maintenance programs, ADIF relies on digital solutions because they are more environmentally friendly and safer for the railway sector. Remote monitoring solutions extend the useful life of infrastructures while meeting safety requirements and improving the reliability, availability and capacity of the railway system. It also minimizes costs and improves the management of the entire asset lifecycle.

Image 8. Clinometer installed on sleeper.

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