**Peter Berger**
Kierownik Rozwoju Działu
Monitoringowego Senceive,
Specjalista od Monitorowania
Infrastruktury Krytycznej

**Michał Dąbrowski**
Kierownik Działu Rozwiązań
Monitoringowych TPI SP z o.o.
mdabrowski@tpi.com.pl

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# How the InfraGuardTM Intelligent Slope and Embankment Monitoring System increases safety in railroads

**Abstract:** A typical solution for the construction of transportation infrastructure around the world is the economic adjustment of their course to the natural terrain. Hence, road and railway construction on embankments or in indentations is typical. Recent climate change is triggering extreme conditions and weather events that have a significant impact on the stability of slopes. Such disturbances may manifest themselves in gradual long-term subsidence, or in sudden, unforeseen landslides and collapses, and constitute a serious threat to human life.

**Keywords:** Monitoring system; Slope; Embankment; Safety in railway issues

## Introduction

Preventive process management is historically often based on local inspection and measurement by one of several classical methods. This is often associated with the need for frequent visits, limited or difficult access to the facility, temporary and irregular measurements - and thus increasing the expenses and risks associated with monitoring using this method.

Current technological innovations have introduced the possibility of automating many of these processes: they have enabled remote access to the facility and related problems, improved the process of obtaining data and managing them, and improved our ability to predict weather conditions - and thus estimating the level of risk related to e.g. with excessive rainfall or sudden thaws. IoT (Internet of Things) technology enabled the creation of InfraGuard™, a wireless intelligent monitoring solution that detects and responds to ground movements and provides early warning of such processes while giving remote access to the system for many users from anywhere in the world. The basic element of such a system is a network of long-life motion sensors, connected to each other and the Internet via a wireless radio platform. Such systems share many IoT characteristics: they are economical, small, easy to install, and require little or no maintenance for a very long lifespan (more than 10 years), do not require mains power, and act as a self-healing system that can withstand damage to individual components. InfraGuardTM networks can integrate motion sensors with wireless robotic cameras and geotechnical survey sensors for additional insights.

This technology has come out of the lab over the past decade and has been widely adopted by users such as UK-based Network Rail, which installed over 10,000 smart sensors in 2020. The same remote health monitoring platforms have now been approved in more and more countries, including Germany, France, Canada, and the USA.

## Risks and challenges

Roads and railways in many parts of the world are built on embankments or adjacent to natural or man-made slopes. The safe and efficient use of these facilities may be adversely affected by the movement of soil, rock, or vegetation in a way that blocks or renders the transport corridor unstable. Failures can manifest as gradual subsidence and deformation, causing disruption and the need for costly engineering intervention, or sudden landslides or rock falls that pose a serious threat to human life.

Factors contributing to the growing interest in monitoring and the growing risk of slope failure include:

- increase in the number of extreme weather events related to climate change, including more frequent episodes of prolonged, intense rainfall - a key factor reducing the stability of the ground
- an increase in rail and road traffic, which increases the risk and severity of an impact on people
- the age of many of the earth formations that were built before design standards – they are poorly drained and too steep by modern standards
- a culture of risk aversion where property managers are under pressure to anticipate and prevent events rather than fix them after the fact.

In this context, we consider the practical usefulness of the classical approach and explore the use of smart monitoring solutions based on wireless remote condition monitoring technology to reduce the risk of slope failure by detecting ground movements and alerting stakeholders. In particular, we describe the application of intelligent monitoring by Network Rail on British railway tracks.

## Risk management and security control - classic approach

Persons responsible for the safety of the facilities carried out inspections and monitored the slopes in particularly endangered places, but the tools and measurement methodology available to them were laborious and often ineffective in providing interested parties with useful and crucial information. In the previous practice of slope management, the monitoring process was based on periodic inspections and research with the participation of people. Geotechnical (subsurface) monitoring was often undertaken in the event of particular concerns about the risk of slope failure, for example using borehole piezometers, inclinometers, and extensometers.

This approach required periodic site visits and manual data logging, and was not only labor intensive but also ineffective in predicting slope failures in advance or notifying users quickly when a failure occurred. Hence the need for a better way of mitigating risk, and wireless remote monitoring is a solution with many advantages while solving many of the problems associated with the classical approach mentioned earlier.

The introduction of modern measurement technology often comes with inherent obstacles and can create other challenges. Location locations are mostly rural and can be at the foot of steep slopes, so they sometimes have poor cellular coverage. Very few places are powered by electricity and access to bring in installation and measuring equipment is often difficult. Most importantly, however, all parties needed to be confident that the system would provide the level of reliability and repeatability necessary for its potential impact on rail safety and efficiency.

## Wireless monitoring solution

## IoT Impact

The emergence of proven, reliable and integrated Internet of Things (IoT) technologies has enabled the development of InfraGuard™, a wireless intelligent monitoring system (IMS) that can be effective in remote locations with difficult GSM communication.

The network of wireless sensors can detect and respond to ground movements, remotely and automatically collect measurement data, correlate them with other variables (atmospheric conditions, traffic intensity, weather forecasts), and, as a result, provide an early warning system for many users in the form of an automatic notification.

The core element of the InfraGuard™ system is a network of long-life inclination sensors connected to each other and to the Internet via a wireless radio platform. Data from sensors are compiled in the Gateway Headquarters (communication gateway) and transferred to the web user interface (WebMonitor) via HSPA+ (3G) or LTE (4G) communication technologies.

**1.** Diagram of a typical InfraGuard™ installation: inclinometers installed on poles on the slope/embankment, FlatMesh camera, and Gateway 4G Communications Center

Such systems share many of the characteristics of IoT devices: they are relatively inexpensive, small, easy to install, and require little or no maintenance over a very long lifetime (>10 years). They do not need wiring for power or communication connections and operate as a self-healing system that can survive damage to individual elements of their network.

## InfraGuard™ Intelligent Monitoring

The InfraGuard™ measurement system presented in the article is built on the Senceive FlatMesh™ intelligent monitoring platform, developed for use in railway earthworks. A monitoring system that can be defined as an IMS has several key attributes. They relate primarily to automation and responsiveness.

FlatMesh™ is an intelligent wireless sensor system based on a "spider" network structure, developed over the last decade by Senceive, which dates back to research conducted at University College London, launched in 2005. The version introduced in 2013 was the first to use edge computing and embedded intelligence in sensor nodes. Until 2015, a variable reporting rate, automatic event triggering, and integrated camera were added, and power consumption was improved, allowing a typical node to run for more than a decade without battery replacement. Intelligent data processing in the sensor node and the ability to make automatic decisions have brought huge benefits and have been used in many remote geotechnical condition monitoring applications.

**2.** Installation of sensors detecting slope sliding in two rows

Sensor nodes can change the reporting frequency, camera nodes can be commanded to take a snapshot, or all sensor nodes in the network can be commanded to take a reading immediately. In the event of exceeding the pre-defined boundary conditions or the occurrence of critical conditions, the Network Central automatically enables the change of measurement and communication protocols to enable a more accurate and reliable measurement process and immediate data transmission to the server.

**3.** FlatMesh IX and NanoMacro 3-axis inclination sensor measures rotation with a resolution of 0.0001° (0.0018 mm/m)

The computational capabilities built into the measurement sensor are the factor that makes the network sufficiently resilient to short- or long-term failures without systematic performance loss. In the event of a short-term power outage, data can be stored onboard the node and forwarded when network coverage resumes. If a node is damaged over an extended period (for example, by being hit by construction equipment), neighboring nodes will automatically adjust to find the most efficient transmission route to the Network Hub.

The key issues regarding the system, which is to play a role related to safety in the railway network, are durability, repeatability, and fast transfer of measurement data.

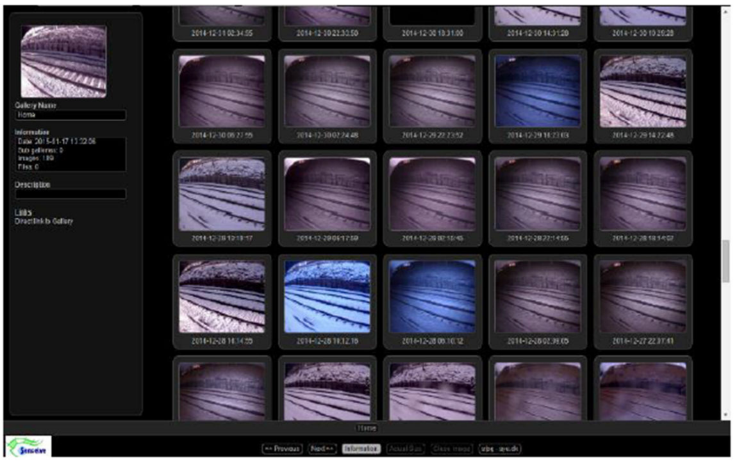
In terms of durability, the monitoring system is expected to operate in all weather and lighting conditions for many years without significant human intervention. The hardware components have been designed and built to operate in environmental conditions beyond those likely to occur in Europe. For example, inclination sensors are designed to operate in a temperature range of -40°C to +85°C. The battery life of the inclination sensors is 12 to 15 years at a typical reporting rate. InfraGuard$^{TM}$ network elements that require external power supply work with a solar panel.

However, a certain degree of human support for the monitoring process is required. It is necessary to selectively remove vegetation to prevent it from contacting the tilt sensors or obscuring the cameras and to clean solar panels in areas where there is tree sap or other precipitation.

The term "latency" refers to the time that elapses between taking and sending a measurement. In the case of a camera, latency refers to the time it takes from receiving a signal that triggers the activation of the camera until the image is available in the web gallery. The typical delay is 1 minute 30 seconds. For an inclinometer, latency is defined as the time from receiving a measurement request to sending a warning to WebMonitor. A typical delay is 2 minutes and 41 seconds.

A key requirement of a monitoring system is to ensure the appropriate level of repeatability of automated instrument measurements to eliminate false readings and misleading alarms that could compromise the system's performance and confidence. Repeatability is defined by the Bureau International des Poids et Mesures as the precision of measurement under specified repeatability conditions. For the IX inclination sensors used in this project, this value is ±0.0005°, which corresponds to ±0.0087 mm/m.

The measurement devices that make up the complete InfraGuard$^{TM}$ monitoring system include a wide range of 3-axis inclination sensors, an ODS laser displacement sensor, a CS feeler gauge sensor, an InfraRed wireless camera, and vibrating string and mV/V transducer nodes that allow third-party sensors to be connected to the wireless system as well as PT100 air and material temperature monitoring sensors.



**4.** An example collage of photos from a FlatMesh camera with an InfraRed infrared module - photos are taken in a daily cycle and sent to the WebMonitor system

All advantages related to the InfraGuard$^{TM}$ intelligent measurement network are available only in the FlatMesh® network communication protocol created by Senceive and due to the lack of bandwidth and synchronization problems - they are not possible to be used in other wireless communication networks, LoRa types, which are used by most the wireless surveillance industry.

## British Network Rail and the introduced InfraGard$^{TM}$ security system

Network Rail owns and operates the UK's main rail network. The basic elements of this network are mostly over 130 years old, including over 190,000 objects, these are the earth elements: escarpments, cutouts, embankments.

Several of these routes have a cumulative combination of features that together result in a relatively high risk of disturbance from escarpment damage: the presence of steep slopes, unstable geology, increasing periods of exceptionally wet weather, and high levels of traffic.

A prime example is the busy commuter lines running south from London through Kent and Sussex, and the managers responsible for them have decided to implement extensive monitoring of cuts and embankments.

### High caliber monitoring in Kent and Sussex

A decision has been made in both Kent and Sussex to invest around £6m in an intelligent earthworks monitoring system, to bring the system into operation ahead of the 2020/21 winter storm season. To make the implementation of the system effective and simple enough to be carried out by non-specialists, a standard approach was applied to each location. Each structure was divided into blocks of 100 m (equivalent to five chains on the traditional British railway system). Each block has 50 tilt sensor nodes, two cameras, and one solar-powered Cellular Communications Center.

**5.** EdgeHub Communications Center, 4G camera and solar panel

In Sussex, tilt sensors were installed 4m apart in two rows at the foot of the slope and two meters above. The team in Kent decided to install one row at the bottom of the slope and one row at the top. In all cases, the sensors were attached to vertical metal posts driven into the ground to a depth of 500 mm. In the shortest locations, only one such block was installed, while in longer locations - several were. The longest, at Haywards Heath, has 20 blocks consisting of 20 gates, 40 cameras, and 996 tilt sensors. A total of 9.7km of troubled slopes were measured in Sussex and 12.7km in Kent.

An installation on this scale has resulted in a significant increase in efficiency. By the end of the project, the entire 100 m long installation could be completed in one shift, meaning only four or five hours of on-site work. This included ecological, topographical, and buried utility surveys, selective removal of vegetation, installation of nodes, cameras, and a solar panel gate, and as-built surveying. The installation of the monitoring system was carried out by contractors without prior experience. Most of the work was done without closing the line.

A standard installation procedure was developed for the project. The system was ready for operation before the team left the construction site, and configuration and validation were done by Senceive employees. The data and documentation were then reviewed and approved by Network Rail's route resource manager and, once approved, passed on to the route control department. The system uses a standard series of alarms based on the scale of recorded motion. They are summarized in Table **1**, with a description of the actions triggered at each level.

**Tab. 1.** List of actions triggered at different warning levels

| Warning level | Sensor movement | Reaction |
|---|---|---|
| Level 1 Green | 10 mm | The engineer remotely determines whether the results are true, informs the monitoring management team, continues monitoring |
| Level 2 Yellow | 30 mm | The reaction above and sending for inspection of the incident site |
| Level 3 Red | 60 mm | All of the above plus notification to the traffic management team of any emergency speed limit being imposed and preventative work being initiated |
| Level 4 Black | 90 mm | All of the above plus stopping the train or being careful in traffic |

Most of the system commissioned in Kent and Sussex in 2020 was operational through the winter of 2021/22.

The InfraGuard$^{TM}$ smart monitoring solution featured in the article is designed to detect slope surface movements and alert users promptly through alert messages. In addition to the tilt sensors used to detect movements, the Senceive FlatMesh wireless monitoring platform at the core of the system can contain several other sensors, including subsurface geotechnical instruments. The Network Rail project described above involved a limited number of borehole piezometers installed in the same system as the tilt sensors and cameras. Although not included in this case study, other instruments that have been incorporated into wireless monitoring systems include vibrating string sensor extensometers and piezometers, the FlexiMeasure IPI automatic inclinometer chain.

## Further development of InfraGuard$^{TM}$ and other Senceive monitoring solutions

Further developments in remote monitoring technology using IoT Senceive sensors are expected to include greater integration of data streams to better predict edge failures and network disruptions. The most obvious candidates are the integration of traffic data with improved weather data and forecasts.

The intelligent monitoring system described above has been developed specifically for use on earth slopes adjacent to railway tracks. It would be less effective where the main problem is a rock fall, as individual rocks of considerable size could fall into the path between the sensors and remain undetected. However, there are other applications where the same type of system could be used. Examples include mine and quarry faces, flood embankments and earth dams, and other elements of critical hydro-technical infrastructure.

**6.** Monitoring system installation

**7.** Other examples of applications of Senceive monitoring solutions in railway tasks