Autonomous IOT for condition monitoring, assessment and predictive maintenance

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Abstract. Rocket NG is a startup with experts from civil, electronic and network engineering. We designed, offer and operate an end-to-end IoT system for condition monitoring, condition assessment and predictive maintenance. The system operates autonomous and is characterized by reliability and simplicity in the application.

One major goal was to ease the installation. Thus, the sensors only need to be mounted on the structure and plugged into the IoT-Node. Neither a configuration nor a permanent power connection is required. The measured values are automatically transmitted (wireless) to the platform, stored in a structured manner, processed, assessed and prepared for display as dashboards in a web browser. Assessments are also possible on the node (edge computing).

In the paper 3 solutions are presented with their sensor layouts, advantages and assessments. The first is a crack monitoring on a structural concrete bridge. The second is a cathodic protection system of a reinforced concrete cantilever. The third application addresses the wetting and drying of chloride contaminated water on a concrete wall beside the highway for the further investigation of the chloride ingress.

Keywords: monitoring, IoT, autonomous, data fusion, Edge Computing, Maintenance Savings.

1 Monitoring of Infrastructure Assets

1.1 Constraints, Requirements and Motivation

The IoT monitoring System presented here is an autonomous and highly innovative system, that brings new opportunities for clients and contractors. The focus during development was on autarky, reliability and easy application of the entire IoT monitoring system. It is optimized for the monitoring of infrastructure and already used in many applications since years.

Infrastructure assets such as bridges, abutments, columns, retaining walls and alike are usually in the field, where no fixed power source is available to power a monitoring system. Additionally, these types of infrastructure are very large in dimension, with widespread sensor positions and therefore installation of data and power cables can be a very tedious and costly work.

1.2 Overview of the Monitoring System

An overview of the monitoring system is given in Figure 1. The sensors and the IoT-Nodes are mounted at several assets, where no power source was available. The sensor nodes read the data from the sensors and send the measurements wireless over the network to the platform (Cloud), where the data is stored and the visualizations can be retrieved via a web browser. The node has much more functions, which are explained later.

The autonomous, low-energy sensor nodes on site are battery-operated, can be flexible arranged and operated with a battery lifetime of up to 15 years (e.g. crack monitoring). Since no fixed power connection is required, there is no need to install long cables for electricity or the network connection. The data transmission is encrypted, automated and with the latest radio technology.

Sensors must be mounted correctly on the object and simply plugged into the sensor node (plug & play). No configuration (network, measurement technology, …) is required on site. The nodes are also equipped with powerful processors, memory and data transmission, enabling intelligent preliminary evaluations (edge computing, AIoT = AI + IoT). The nodes are also prepared to exchange data and communicate between themselves (mesh) and trigger actions in the mesh.

The measured values of the sensors are transferred to the platform, stored in a structured manner, processed and prepared for display on dashboards in a web browser. The platform is based on a redundant time series database, which is operated on our own hardware in two data centers. It is also possible to integrate external data sources for evaluation and analysis with models. In addition, critical states or impending critical states can be automatically determined and information/alarms can be sent to the responsible persons or groups via email / SMS / ...

Figure 1: Schematic representation of the monitoring system.

The entire system is automaticaly monitored continuously for proper functioning of the sensors and node. Thus, there is no need for monual. The system notifies the user when a problem occurs. We call this function “plug & forget” because you do not need to think about it during normal operation.

1.3 Description of the Sensor Node

The node is in a very robust casing and withstands the harsh environment that is often encountered at such infrastructure. An image of the node is given in Figure 2. The dimensions of the node are 16x11x7cm with 1, 2 or 6 possible sensor connections.

The configuration of the sensors, the ADC (analog-digital converter) is usually a tedious task that needs to be done by measurement technicians, which is not necessary with this system. Here, the sensors can be equipped with a special plug (containing all the information of the sensor) that installs the sensor just by plugging into the node. No additional configuration is necessary, which is an enormous simplification during installation and cost saving factor.

Figure 2: Autonomous sensor node with external antenna.

Further, the node is also “always ready” and the network configuration to transfer the data is also done automatically. Thus, no configuration for data transfer is necessary during installation, which eases the installation even further.

Important during the installation process is that the sensors are positioned appropriately, so that the sensors can perform their measurements precisely. Installation of sensors is not difficult but requires experience and some knowledge for long lasting installations. The same holds for designing monitoring layouts.

Nearly all sensors available on the market can be connected to the node. An important factor to consider is the energy consumption of the sensor, that has a direct effect on the battery lifetime. Most sensor types have a low energy alternative that should be preferred.

The system uses low-power microprocessors and low-energy mobile radio transmission to enable a very energy efficient sensor node. However, the components used are low energy but highly qualitative components and among the most accurate in the field. Calculations and the tests in our labs show that for a monitoring of crack widths measurements and transfer every 15 minutes the battery lasts for about 16.7 years (approximately 15 years, as mentioned earlier).

The sensor node is also able to operate at different modes, e.g. wake up due to special events, intelligent data recording, several measuring modes, data evaluation by edge computing, …

Additionally, the nodes work independently of each other and can be positioned on the structure as required. They collect the data and send it to our data platform via LoRaWAN (radio connection) to gateways and then to the database. The transmission range of the sensor nodes with LoRaWAN is about 1.5km in the built-up area and at least 20km in the unobstructed area. On the platform the data streams can be combined with other sources (data-fusion), injected into models, evaluated and assessed. Finally, the data and the results are clearly presented in intuitive to use dashboards, which can be accessed by an ordinary web browser. The users can view the visualizations of the measurements and analyze the data with simple self-explanatory mouse-clicks. Models can be implemented for specialized investigations and evaluations, they do an automatic evaluation of the data, trigger alarms and notify the users. The time from the measurement to the arrival on the platform is only several seconds.

2 Application Examples

2.1 Crack Monitoring

Figure 3 shows the web dashboard of crack monitorings at two bridges. The measurement positions are clearly indicated in the upper left photograph, while the other two show the details of the crack including the current measurements. The two graphs below show the change of the crack width together with the concrete and air temperature. The table on the right gives the min and max-values in the selected time interval. The time interval is here two days, which can be changed by clicking the pull-down menu on the upper right.

Interesting for the assessment of the crack width is also the change due to temperature. This part of the dashboard is shown in Figure 4.

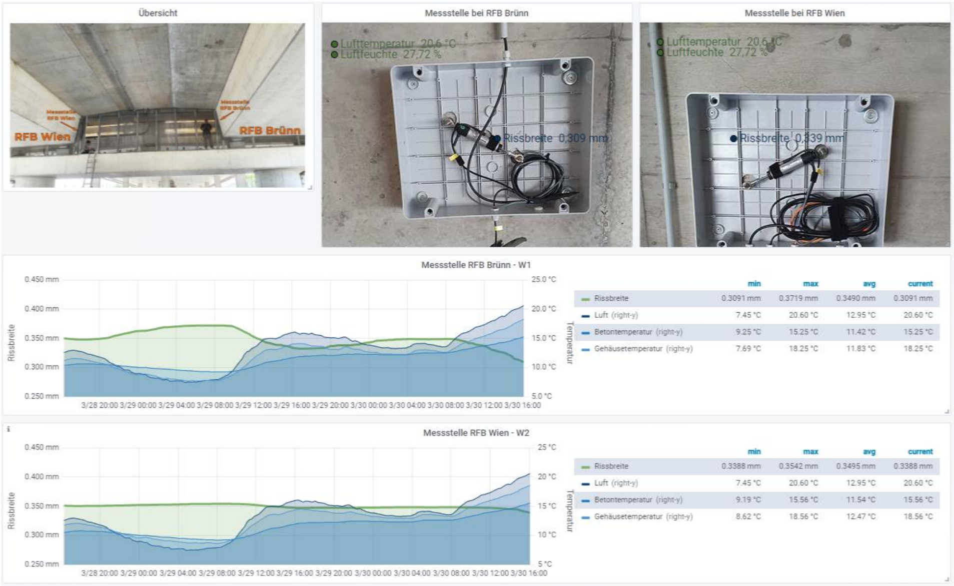

Figure 3: Dashboard of crack monitoring with measurements of two days – Detail.

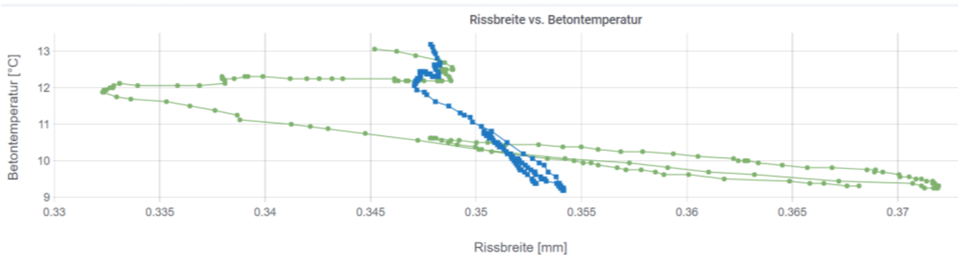

Figure 4: Dashboard of crack monitoring (green: RFB: Brünn, red: RFB Wien) – Detail: crack vs. Temperature.

2.2 Monitoring of the water transport in a concrete wall beside the highway

This monitoring is part of a research project for the determination and evaluation of chloride ingress into concrete structures, which is further described in [1]. Figure 5 shows a detail of the dashboard. One can see the temperature fluctuations at two levels on the left and their corresponding humidities on the right. This data presentation is enhanced by histograms to further assess the variation in the selected time interval. In case another time interval is selected the entire dashboard updates and displays the corresponding time series and histograms. This data together with other chemical analyses and measurements will be the basis for a Chloride ingress model and a Chloride prediction model.

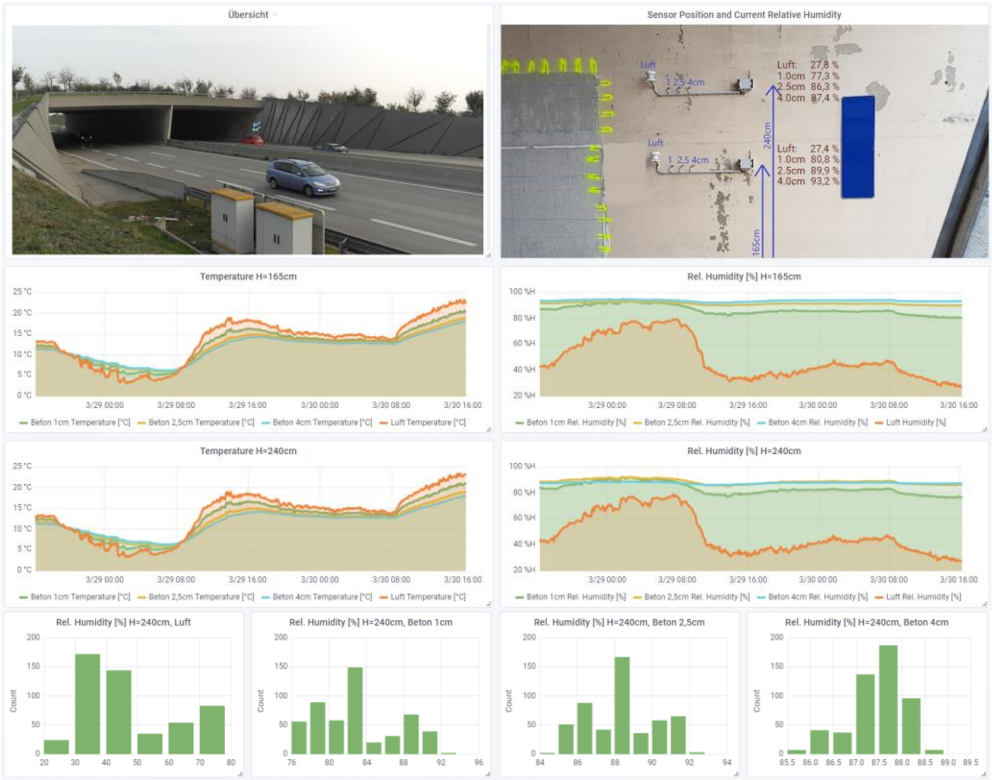

Figure 5: Monitoring of humidity and temperature in concrete wall.

2.3 Monitoring of a kathodic protection system

The third application presented is the monitoring of a galvanic cathodic corrosion protection systems (KKS) with zinc hydrogel foil for permanent prevention of reinforcement corrosion installed on a chloride-containing concrete cantilever, see Figure 6.

The monitoring system of the KKS is compliant to the ISO 12696:2016(E). For that purpose, two reference electrodes, two cable connections for reinforcement and two anode connections were installed. Figure 7 shows the measurement of the electric potential, corrosion current and status of the KKS. These values are continuously monitored and critical deviations of the values trigger an alarm. Additionally, the KKS must be switched off at certain intervals (requirement according to standard ISO 12696:2016(E)), as can be seen in the graphs. The drop of the electric potential needs to be measured in an interval of 100 milliseconds during switch event for evaluation of the proper functionality. The switching of the KKS is done by connecting the zink (anode) and the reinforcement (cathode). The sensor node works at this application in several states. On one hand the measurements were taken at intervals of 10min and transferred to the platform. Before switching the KKS to off the measurement interval must be increased to 100 milliseconds, then the KKS is switched off and the measurements must further collected at the 100 milliseconds interval. The measurement at the high interval is only during switching and lasts for about half a minute in total. After 24 hours the KKS is switched back on (suspend the connection between zink and reinforcement) in the same procedure. Prior to this system the switching and the measurements had to be taken by a person on site with equipment installed for that purpose and continuous online control of the corrosion protection system was not possible.

Figure 6: Galvanic cathodic corrosion protection system with zink hydrogel foil for prevention of corrosion reinforcement - Detail of the dashboard with electric potential between reinforcement and electrodes.

Figure 7: Electric potential of the reinforcement, current, KKS status on or off.

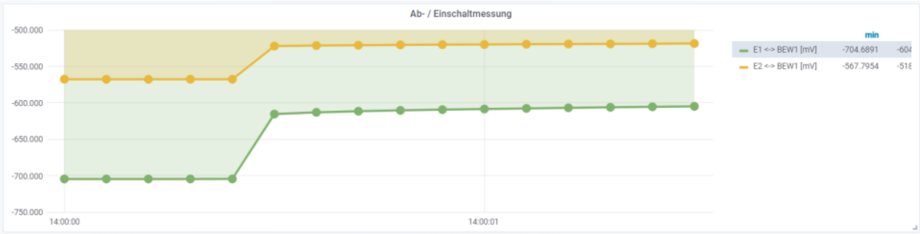

Figure 8: high resolution measurement during switch-off event

3 Conclusions and Potential Applications

From the description of the monitoring system above and the examples shown, the advantages of this monitoring system can be summarized. The advantages due to the simplified installation are:

- For the installation only knowledge for a professional assembly on the structure is required, no knowledge about measuring technology is necessary ("plug & play").
- There is no need for a power supply or network connection on site, this reduces the planning effort and enables monitoring next to roads, trains, but also in rough terrain.
- No measuring cables have to be installed, as the data is transmitted via radio.
- The susceptibility to errors is reduced by a standardized system and the omission of necessary measurement settings.
- During installation an estimate for the appropriate measurement frequency, for trigger values and other model parameters for assessment can be given and adapted remotely after a first evaluation of measurements.

The advantages during operation are:

- The condition / status of the sensor, the battery and the transmission parameters are up-to-date and checked together with the health status of node and sensors ("plug & forget").
- The system enables real-time alarms via email, SMS or APP

These advantages give a new group of customers access to measurement technology and monitoring. By moving away from the much more complex measuring PC to the microprocessor, attractive prices can also be expected.

References

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