CONDITION MONITORING IN ROAD TUNNELS

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ABSTRACT

Industry 4.0 makes available the intelligence of field instruments for road tunnel operators. This enables smart services like *Condition Monitoring* and predictive maintenance. *Condition Monitoring* and predictive maintenance increase service efficiency and effectiveness. It gives the maintenance team and operators the possibility to have a clear and continuous picture of the technical condition of the installed equipment in the tunnels. The tunnel operator can save resources and time by grouping maintenance requirements of different equipment classes, organizing maintenance interventions based on the actual requirements rather than on time based schedules and enabling optimized service interventions by knowing the source of the problem before going to the equipment. The SICK *Monitoring Box* offers an easy to integrate solution for *Condition Monitoring* for existing and planned road tunnels.

Keywords: Condition monitoring, tunnels, predictive maintenance, industry 4.0, internet of things (IoT), air quality,

1. INTRODUCTION

In tunnel projects, the traditional focus for tunnel automation is the design of the control system. Mayor attention is drawn to the design and function of the control system along the automation pyramid. The maintenance aspect is typically not the focus in the automation system design phase. Considering the long lifecycle of electrical equipment of about one and a half decade the operational phase in a tunnel lifecycle is an interesting issue. A favored maintenance strategy in the operation phase of a tunnel is preventive maintenance (Urs, Wierer, & Buraczynski, 2012).

Preventive maintenance (in the sense of systematic maintenance (Martin , et al., 2012)) bases on considerations of the probability of a failure at a certain time. This approach does not consider the actual state of an entity as such. It is part of this approach to count with (less probable) unplanned or unexpected asset failures and breakdowns. These unexpected failures can require a timely intervention of the service team and trigger lane or tunnel closures. These closures decrease the availability of the tunnel for the tunnel users.

One of the characteristics of the equipment used for tunnel ventilation is its installation inside the traffic section of a tunnel. Access to the equipment is difficult and in many cases not possible under flowing traffic. In most tunnel projects, the connection to control equipment like air quality and air speed and direction sensors is realized through analogue and digital outputs. In case of an equipment failure or maintenance signal the service team has no mean to know the actual cause of the failure. Only after physical presence at the sensor, the service team member knows what kind of intervention the equipment requires. In case the required parts and tools are not available in that moment an additional service intervention might be required.

To have spare equipment on site in for exchange in case failure increases the capital expenditure and has the inherent risk of stock damage.

With preventive maintenance, service interventions are time based. Good practice is to choose a shorter service interval to be on the safe side. As the service does not consider the state of an entity, service interventions might be triggered which are not necessary for this entity (e.g. cleaning of optical surfaces).

2. CONDITION BASED MAINTENANCE

In order to increase the availability of the measured values and analyzers, vital data and measured values of the analyzers installed in the tunnel are read directly from the respective devices via various protocols using the *Monitoring Box* and visualized in a *Condition Monitoring* Dashboard. This creates a permanent and detailed overview of the current device status. Compared to preventive maintenance, maintenance work can be carried out in a condition-oriented manner. This saves the tunnel operator time and reduces congestion by minimizing unplanned closures.

An online dashboard visualizes the vital data in real time. The display allows easy interpretation of the current status of the analyzers in a tunnel (see Figure 1).

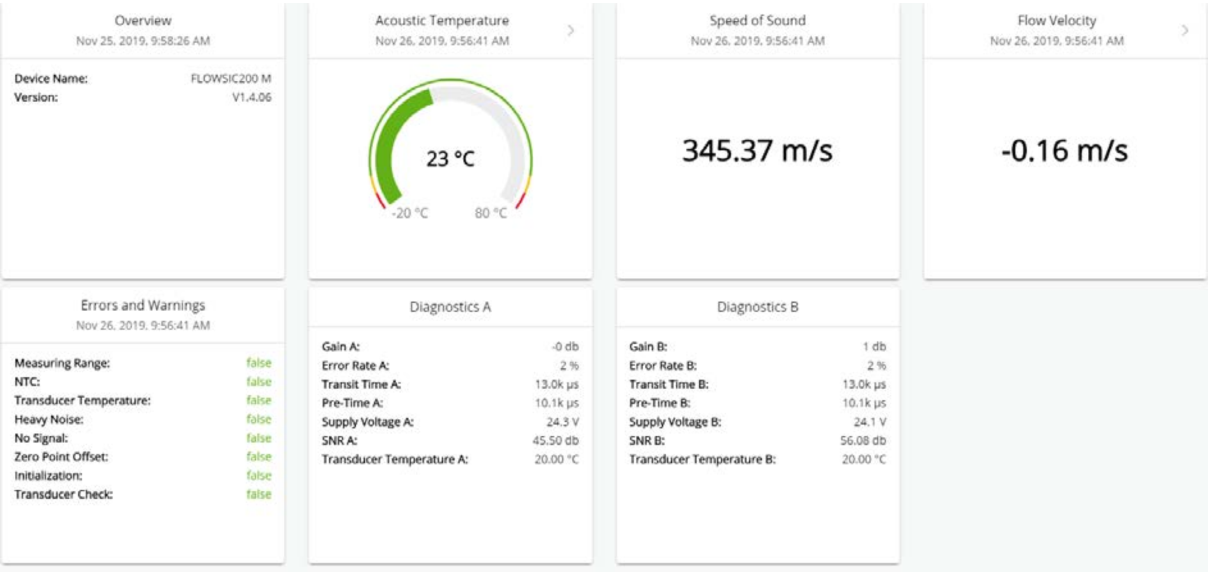

Figure 1: Condition Monitoring Dashboard Widgets

To simplify the interpretation of the data shown, defined thresholds are used. The thresholds are device-specific and are pre-defined (e.g. contamination above 40%).

If a threshold is exceeded, this excess is visually displayed in the first step (e.g. value is displayed as yellow or red) and then an alarm is triggered. This can trigger different responses from the condition monitoring system for the maintenance team. For example it can get informed about the exceeding of the threshold value by e-mail. Through this response the maintenance team is always informed about current exceedances and problems in the device, even if the it does not actively access the dashboard. In this way, a service team can easily keep track of the status of several devices and tunnels and is always informed about the current status.

If threshold values are exceeded, the live data is used to determine the cause of the exceedance. The early and accurate detection of error causes helps the operator to act preventively before major damage can occur to a device. A short maintenance period can prevent a costly service call. This not only saves time and money, but also reduces unplanned closures of tunnels, thus improving smooth tunnel use.

In the *Condition Monitoring* Dashboard, the data of all analyzers of an operator are grouped into assets and tunnel sections. Such grouping allows for the aggregation of the respective device states. Should a problem or failure of a device occur, the necessary work can be combined with other work that is required, which can be derived from the real-time data from the dashboard. This increases the efficiency of service interventions and saves costs and time.

The planning of cyclical maintenance work is also simplified by condition monitoring. By providing a constant overview of the status of the equipment installed in a tunnel or tunnel section, it is possible to plan and prepare the measures necessary for cyclically planned maintenance. Based on the data from the dashboard, it is possible to distinguish which tasks need to be performed acutely and which can still wait until the next maintenance.

Such a preparation can avoid unnecessary service work, save costs for maintenance work and minimize the time for the necessary tunnel closure. By taking a long-term view of the equipment conditions, the planned maintenance cycles can be optimized to keep the unrestricted tunnel use as long as possible.

2.1. Help for the planning and execution of corrective action

In addition to measurement and vital parameters, error codes and maintenance requirements are read from the devices and visualized in the *Condition Monitoring* Dashboard. Should such a message occur, not only the message in detail but also a corresponding Service Note is displayed. A Service Note describes the steps and actions that a service technician has to take to repair the respective damage or carry out maintenance. Thanks to these Service Notes, preparation for troubleshooting is made much easier, as all the steps to be carried out and the spare parts required in each case are already known before the device is visited.

Accurate preparation for service calls means that a sensor can be repaired on the first service intervention inside the tunnel. This means time and cost savings for the tunnel operator.

Since several devices of the same type are typically installed in a tunnel, the internal data of the individual devices in this tunnel can be compared with each other. If one of the devices changes, this change can be detected and evaluated by the *Monitoring Box*. In the same way, changes of individual devices can be analyzed and their future behavior can be predicted. For example, an increase in pollution typical for the tunnel or installation site can be detected and the wear rate, i.e. the time until probable failure, can be determined.

2.2. Condition monitoring is scalable

In addition to the connection and monitoring of the analyzers for air quality measurement, the *Monitoring Box* from SICK also offers the possibility of integrating other electronic equipment in a tunnel into the system. It is possible to connect light sources, fire dampers, and other sensors in the respective tunnel or tunnel section and monitor their status in the *Condition Monitoring Dashboard*.

2.3. New developments of condition monitoring

In addition to the visualization of parameters, the *Monitoring Box* will in future also take on the function of documenting and logging service and maintenance operations carried out as proof or evidence for the quality management system. If changes are made to a device, the *Monitoring Box* documents the condition before and after the intervention. It is possible to record which electronic card is installed before and after an exchange, the dirt level on optical surfaces before and after cleaning, what the factors are before and after an adjustment, how many steps a stepper motor has available again for a device for self-alignment before and after a realignment. It thus records what has changed and how much.

3. TECHNICAL ASPECTS OF CONDITION MONITORING IN TUNNELS

3.1. Existing tunnels and actual tunnel projects

Most of the past and actual tunnel projects connect air quality instruments and smoke detectors through analog and digital outputs to the tunnel automation system. The transition from analog signals to Ethernet follows in the next level of the automation pyramid after the PLCs (Figure 2).

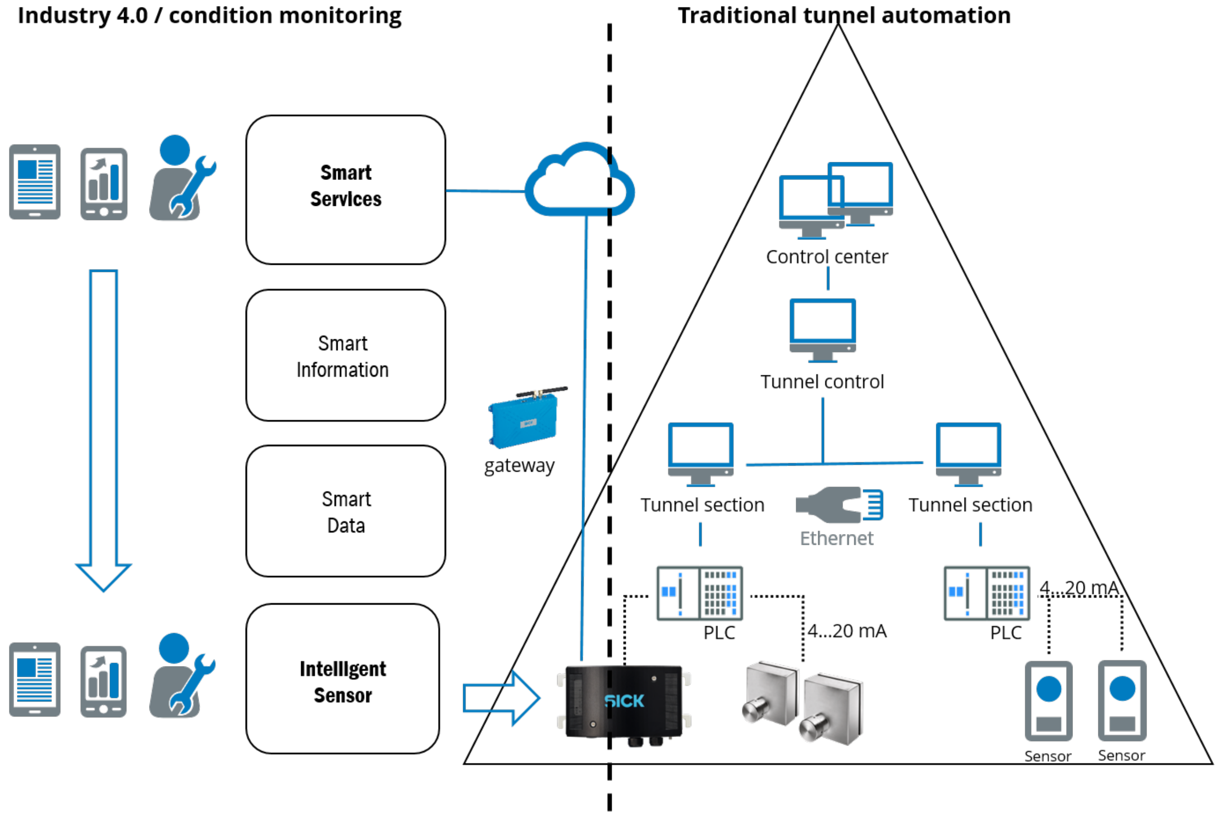

Figure 2: industry 4.0 vs automation pyramid in tunnel automation

The connection through analog and digital outputs limits the data transmission to measuring and status values. No internal instrument data is available for the control system and or the tunnel automation system.

To make internal data available for smart services like condition monitoring there is a need for a second data channel. Accessing the second data channel is mostly possible without passing through the PLC level. Through this additional data channel, a middleware retrieves field-device internal-data and feeds this data into a data storage. This data storage can be realized as a data- base in a cloud storage. The middleware also converts company specific or standard data protocols like Modbus into industry 4.0 or IoT protocols like MQTT or OPC UA. For the transmission of data into the cloud data storage, a cloud gateway is used. Smart-service software accesses the storage database and combines the data with instrument specific knowledge to generate useful information for the tunnel service team. In the case of condition monitoring as a smart service software, it also presents the information in an easy to use dashboard. For cybersecurity reasons the cloud gateway is limited to data retrieval of the field instruments. It is not possible to perform changes in the connected instruments. The analog connection from the field devices to the control system perfectly separates the smart data channel of field device like an air quality sensor from the control system. There is no connection between the sensor network and the tunnel control network. Furthermore the data transmission from gateway to server is end-to-end encrypted via HTTPS.

3.2. Future tunnel projects

The data transmission in tunnels is typically TCP/IP based. This allows for the use of the tunnel automation network also for the transmission and data-storage of device internal vital data through or within the tunnel control network. We expect that in future projects it is likely to see such an on-premise realization for smart services like condition monitoring as a requirement in the project description of the tunnel project.

4. SUMMARY AND CONCLUSIONS

Condition monitoring is an industry 4.0 application that can improve the efficiency and effectiveness of maintenance in road tunnels. Through the collection, storage, analysis and visualization of constantly generated vital data of field devices it offers an important contribution for the switch from time based maintenance to condition based maintenance.

5. REFERENCES

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