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The Role of Automated Monitoring Systems: how to avoid being data-rich and information-poor

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Abstract

Technology advancements in sensors, data acquisition systems, and software over the last decade have allowed engineers to deploy sophisticated monitoring systems on critical infrastructure projects around the world. These monitoring systems often contain hundreds, or even thousands of sensors capable of providing real-time performance data through well synchronized data acquisition systems and visualization software.

While automated monitoring systems have greatly reduced the amount of engineering resources spent on routine tasks such as collecting data, processing raw data, and generating data plots, these resources are not always reinvested in tasks such as data interpretation and questioning what the data are really showing. Modern monitoring systems are generally easier to install and maintain making them more attractive to non-experts. As the number of sensors and the frequency in which the sensors are being read have increased significantly, challenges in translating monitoring data into site performance and actionable insights have emerged.

This paper explores the role of automated monitoring systems, how they should be implemented to meet the monitoring goals of a project, and tips on how to avoid being data-rich and information poor.

Keywords: Monitoring, Automated Data Collection, The Observational Method

1. Introduction

With a growing awareness of the benefits of instrumentation, the greater adaptability of new technologies, and the need for reliable and timely delivery of data, the number of sensors installed on any project has increased significantly in recent years. In many cases the number of sensors surpasses the ability to manually collect (and interpret) the data, and stand to benefit from well-designed automation systems, or simply require real-time monitoring to forewarn of impending hazardous situations.

Today, the cost, reliability and ease of automated monitoring is far less than it was in the past, making it possible for even relatively small projects to enjoy the benefits; and in some cases, has allowed the use of even more sensors for a more thorough evaluation of structure performance. This said, no automated monitoring system will ever replace sound engineering judgement, the input from an engineer with boots on the ground. Site visits, while often brief, allow for visual inspections which can provide critical information that reviewing large data files would never be able to accomplish. And to this point, a manually read monitoring program requires staff to go into the field to access the sensors and “observe”.

In the past, there were specialist companies, with experts, practicing in the deployment and monitoring of instrumentation systems. Recently this task is often left to inexperienced (low cost) personnel, with a limited understanding of not only the project and the sensors but of the purpose of the instrumentation itself. These inexperienced instrumentation personnel often put misplaced expectations on the instrumentation manufacturers for support, resulting in manufacturers employing additional experienced civil, geotechnical, and structural engineers to support the sale of their products. Automated systems serve to relieve some of the burden of monitoring placed on project owners by delivering reliable, timely, data retrieval, without disrupting construction activities and by providing the opportunity to identify areas of concern quickly and to implement requisite remedial measures. Additionally, the advent of wireless network systems allows for rapid redeployment or expansion with minimal impact on the existing system or, more importantly, on the construction itself.
The key to any successful monitoring project, automated or manual, relies on careful planning, correct execution, and an action plan (or plans) to implement the needful based on the data delivered. Peck's Observational Method outlined the philosophy behind most monitoring programs and which Dunnicliff went on to supplement with a detailed, systematic approach. In short, Peck purported to define the geotechnical questions that need to be answered, and then to select instruments and their placement to assist in answering that question; if there is no question, then there is no need for instrumentation. And Dunnicliff augmented by stressing to define the purpose of the instrumentation; that it should not be used unless there is a valid reason that can be defended.

2. Selecting a Data Management System

When planning an instrumentation and monitoring program, it is important to select an appropriate data management system that fits the needs of the project. Data management systems range from the most basic forms consisting of hand field notes to collect raw data and excel spreadsheets to calculate engineering units, to sophisticated automated data collection systems consisting of wireless data transmission, automated graphing, alarms and triggers and even artificial intelligence. The process outlined below will guide the system designer through selecting a data management system that is appropriate for the project.

2.1 Identify the parties involved and the needs of each party

The first step in selecting a data management system is to identify the parties involved in the project, and the needs of each party. Depending on the type and size of the project the interested parties may include:

- Owner
- Engineer of Record
- Design Engineer
- Regulatory Agencies
- Construction Contractor
- Instrumentation Manufacturer
- Instrumentation Installation Personnel
- Monitoring Contractor

2.1.1 Owner

The owner’s needs may be as basic as just knowing that the other relevant parties have access to critical performance data or may be complex, requiring the owner’s technical team to have access to real-time visualizations of all monitoring data. In some cases, the owner may have pre-selected, or even proprietary data management platforms that data will need to feed into. In many cases the owner’s software requirements may limit the selection of data acquisition systems and/or the sensors that can be used on a project. As much as instrumentation manufactures and contractors would like to use a bottom-up approach (i.e., select the sensors and data acquisition systems that are most appropriate/preferred for the project), that cannot always be the accomplished where the owner has existing data management systems in place. Another critical evaluation step in selecting a data management system is to evaluate the owners IT infrastructure and any policy/firewall restrictions that may limit the use of commercially available systems (e.g., cloud data hosing, browser visualization platforms).

2.1.2 Engineer of Record

The Engineer of Record (EoR) has become an important role, especially in the dam safety industry. The EoR may be independent from the design and construction firms, however, will require access to instrumentation data on a regular basis to ensure construction and operation of the structures are be carried out in accordance with the design intent and all applicable regulations and guidelines. The EoR may have requirements for data collection frequencies, data plots, and thresholds/trigger limits on instruments. Selection of a data management system should take these requirements into consideration and make these easily accessible to the EoR. In some cases, instrumentation databases may not have the tools required for the EoR to interpret that data effectively, requiring costly data exporting, reprocessing and reploting using inefficient tools (e.g., Excel).

2.1.3 Design Engineer

The design engineer requires insights into performance of the structures being constructed to evaluate that the design assumptions are validated in the field. It is important that instrumentation data be readily available
alongside construction data so that quick decisions can be made regarding design changes and construction sequencing if required. The advancement in real-time data systems for field instrumentation has allowed that observational method to be used in more projects which can reduce construction costs and timelines of large construction projects.

2.1.4 Regulatory Agencies

An emerging project requirement is that instrumentation and monitoring reports be submitted to various regulatory agencies on a regular basis (i.e., weekly, monthly, quarterly, yearly). Regulatory agencies may have their own requirements regarding the data they want to see and as such it is important to have a data management system that allows flexibility in reporting. Many systems allow multiple automated reporting functions to allow the user to configure a specific report that complies with the requirements of regulatory agencies.

2.1.5 Construction Contractor

Many instrumentation and monitoring systems serve as part of the site health and safety program to protect the workers and adjacent infrastructure. For these systems to be most effective onsite warning systems need to be available to alert the construction crews of any danger. Many monitoring systems allow for site alarms that are either set through local hardware, or through a secondary device that can be triggered remotely based on the sensor threshold rate of change. This type of local alarming can be complex and requires careful consideration of both hardware and software.

2.1.6 Instrumentation Manufacturer

Most instrumentation manufacturers offer standard sensors and data acquisition systems that are compatible with a variety of third-party software platforms. In many cases the compatibility of sensors, data acquisition systems, and software is limited based on demand and resources to complete the integrations. If a client developed software platform is to be used on a project, it is best to confirm the integration with typical sensors and data acquisitions systems and allow for appropriate integration time before the project starts if there is integration work to be completed.

2.1.7 Instrumentation Installation Personnel

It is always prudent to consider who will be installing and commissioning the instrumentation and data acquisition as part of the planning process. If local site staff will be doing some or all of the installation, training may be required for both the sensor installation and connection to the data acquisition system. Modern data acquisition systems often make use of complex telemetry configurations that require careful planning and equipment consideration prior to ordering and deploying the system. Even experienced instrumentation contractors may not be so well versed in certain types of instrumentation and data acquisition systems, so it is always important to consider training from the manufacture as part of the implementation.

2.2 Determine which data management system is appropriate for your organization/project

Once the stakeholders have been engaged and the requirements for each interested party has been identified, the level of sophistication for the data management system can be set. It is crucial that the appropriate resources to implement and maintain the system are identified and budgeted to ensure success of the project. Selecting a complex system with limited resources to implement and maintain it will have a lower success rate than selecting a basic system. Selection of an appropriate data management system may require prioritization of stakeholder requirements to fit the project budget.

Data management systems typically fall into 3 categories: manufacturer specific, manufacturer agnostic but installer specific, and manufacturer and supplier agnostic.

2.2.1 Manufacturer Specific Software

Many instrumentation manufacturers offer some form of visualization software to support their products. This software is developed with their own instruments in mind but may offer some integration with other manufactures (e.g., vibrating wire data tends to be very similar across all manufactures). These types of software platforms are typically low cost, or even no cost, and can be suitable for smaller projects, or projects that do not have a large variety of sensor manufacturers. When evaluating manufacturer software look for products that are developed and supported by an in-house software team which are typically better geared toward
geotechnical and structure features and may also offer some project specific customization as part of their ongoing upgrades.

2.2.2 Manufacturer Agnostic/Installer Specific Software

Many monitoring companies have developed their own proprietary monitoring software that they offer as part of a turnkey monitoring package (supply, install, monitor). These products are typically full feature offerings which integrate sensors, data acquisition systems, and other site data across many manufacturers. The monitoring system is set up and configured by an in-house expert, typically with similar project experience. These systems work very well for large-scale, short-term construction projects which require quick uptime, high frequency data collection, and detailed reporting to many stakeholders. These software offerings are typically higher cost and may come with a commitment to the monitoring company for the duration of the project.

2.2.3 Manufacturer and Installer Agnostic Software

Over the last 10 years many software companies have emerged in the geotechnical and structural monitoring space. Many of these companies were founded, owned, and lead by software experts outside of the geotechnical and monitoring space. As these companies matured, they have been able to take experience from other industries and apply them to the geotechnical and structural monitoring space. This has resulted in powerful and user-friendly software offerings that can be utilized by non-experts with minimal training. Once a requirement to write code to set up a monitoring system, these companies have created sensor, data acquisition system, and database integrations that do all the work for you with a few clicks of a mouse. These types of software platforms are ideal for many projects, from short term construction projects to long term asset monitoring. One downside is that the software tends to be offered as an out of the box one size fits all solution, and customization may be expensive and time consuming if it is offered at all.

3.0 Data Presentation

Automated monitoring systems, by their very nature, can collect enormous amounts of data, often in short time periods. This has the advantage that it can identify the onset of certain events with respect to specific time stamps and, as data storage is relatively inexpensive these days, is an attractive option. Additionally, stored data can be made available to various stakeholders for use in a variety of visualization platforms.

Regardless of the automation system deployed (even if a manual system) the data is of little value if it is presented to the owner or stakeholder in a table or as numbers in columns of raw values in a file. As Dunnicliff would insist “Plot it!”

Ideally the plots should bring the subject front and centre. Any major trends or defining metric should be immediately visible and understood. Traditionally plots were generally in the form of line charts however, today, with data visualization platforms becoming more prevalent, histograms and bar charts are also used. The latter are instantly readable and particularly useful for rapid scanning and, because they are space-efficient, can easily display three or four different metrics in a space a little larger than that of a single bar chart.

Line charts are the preferred medium for viewing patterns over time and to present complicated relations into something meaningful. Line charts assist in aspects of data screening, allowing lines of best fit to be made and to remove (if allowable) obvious outliers. They’re also useful for comparison of values and distributions and allow viewers to quickly digest the information being presented to narrow down on a single date/attribute. A few ground rules apply

1. Choose scales so observations fill the space available over the anticipated range
   a. Do not use exaggerated scales which can make minor changes look alarmingly large
2. Plot elevations and depths on the vertical axis
3. Maintain consistency of scales, so plots can be easily compared
4. Plot predicted behaviour (or safety limits) on the same axis as the field readings
5. Create plots showing measurements and observations on the same graph
   a. e.g., pore pressure increases vs height of fill
6. Wherever possible, include baseline data, to identify pre- and post- construction activity

When preparing your graphs keep in mind your audience and add labels and notes to make sure everyone understands what they are seeing.
Another important aspect of generating useful plots is the scale. Many software programs use auto scale features, which can create a false narrative that the readings are fluctuating more than they really are. It is important to consider an appropriate scale for all plots. Scales should be set based on a threshold limit, or minimum scales that are based on the accuracy of the instrument. Figure 2 shows IPI data with the instrument error bands overlaid. Plotting error bands allows the viewer to quickly determine if the change in data is a result of an actual change in field condition, or if the changes are within the error band of the instrument (i.e., sensor noise).
If presenting to a group, or when utilizing a data visualization platform, create dashboards to show the key data, keeping in mind that dashboards can be completely self-sufficient too, even if you are not there to narrate yourself.

4.0 Interpretation and Reporting

Large construction and operation projects often employ specialty teams (either contractors, or owner teams) that are responsible for delivering the monitoring data to the stakeholders, hopefully following the methods outlined in the above sections. Once the monitoring data has been prepared properly, the next critical step is to interpret the data alongside other critical site information. Too often, a room filled with engineers will spend hours looking at wavy lines on a graph trying to decipher what is wrong with the instrument. In isolation, monitoring data can provide some insights into the performance of the site, but to gain the true benefit the data must be viewed with other information such as, construction data, metrological data, geotechnical investigation logs, design drawings, design models, etc. The monitoring team is not always integrated into the project team making data interpretation more complicated than it needs to be. A good project team will have the monitoring team present in key design, construction, and operations meetings.

4.1 Use of Automated Alarms

A common feature of automated monitoring systems is the ability to set alarms and triggers. This feature can prove to be valuable especially on projects with many sensors. There is however a tendency to set arbitrary alarms without real thought as to what an actionable level might be. Having a feedback loop between instrumentation and site activity is critical when deciding on alarm levels. Alarm levels should be set such that an "orange" or early alarm can be triggered to give sufficient time to dig into the monitoring data, along with any other relevant site information to determine if the data are showing an actual issue with the performance of the site, or if the sensor has been triggered by an external factor. External factors that can affect sensor
readings can include localized construction damage to a sensor, failure of the sensor itself, poor data readings from insufficient power to the logger, and poor telemetry communication amongst others.

4.3 Questionable Data

Often the first reaction to unanticipated readings is to reject them and blame the sensor, however the data may be real and may be telling you something important. It is always best to trust the data but verify the readings are correct. Ask yourself, “Can I think of a hypothesis that is consistent with the data.” Spending time determining what might have caused a particular change in readings can prove to be valuable and will often uncover changes in localized geological conditions, construction activity, or performance of a structure that may not have been known before. If you are still at a loss to explain unanticipated readings consult with the manufacture’s technical team to review the data and verify that the instrument is returning valid data. Most reputable manufactures have a team of experienced engineers that most likely have come across similar data.

5.0 Summary and Conclusion

In the last 10 years, modern automated monitoring systems have provided information to inform site decisions which have contributed to the health and safety of those working on critical projects and which have saved time and money on the construction and operation of these assets. New technologies have emerged around sensors, data acquisition systems, and cloud computing platforms which allow for many new players to enter the market without having the wealth of experience which historic players have gained. Modern monitoring programs now consist of many more instruments which are read at very high frequencies. This creates large data sets which if not managed with an appropriate data management system will result in the user being data rich, but information poor. Despite all the advancements in technology in the geotechnical and structural monitoring space, those Ralph Peck and John Dunnicliff quotes from decades ago still ring as true as ever:

“Every instrument on a project should be selected and placed to assist in answering a specific question: If there is no question, there should be no instrumentation” - Ralph Peck

“Instrumentation should not be used unless there is a valid reason that can be defended” - John Dunnicliff

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