The 4th industrial revolution, how monitoring and risk management in constructions is changing in the digital era.

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ABSTRACT

Modern monitoring systems are nowadays more and more good examples of “Internet of Things” where sensors can be smart and communicate to each other and share results over the web using interfaces that are focused to present computed and already filtered data as useful information to allow the human element to take the best decision.

This optimization of the risk management is the same reason of the proven effectiveness of embracing the digital revolution in the construction lifecycle with the aim to reduce to the minimum the risks of delivery a project not on time or on budget implementing a more connected data strategy.

Real-time data before, during and after construction from a monitoring solution can play a critical role to enrich the data model and increase efficiency.

Automated monitoring solutions innovations have been traditionally driven not only by advancements in measuring technology but also by the availability of new telecommunications or computing solutions.

Thanks to the computation power of modern hardware and new software algorithms, automated scanning processing and the real-time surface comparison are now possible.

High-resolution imaging for monitoring is as well now possible thanks to faster telecommunications infrastructures saving time and money for site inspections and visual checking that can now be done remotely.

Measurements from different sensors can now be integrated into the field via wireless mesh and computed securely in the cloud with no risk of hardware failures or data loss.

From the cloud, the measurements are shared in real time through powerful interfaces that allow data to be presented as useful information for people in charge and site engineers.

The latest monitoring innovations and real case studies, examples and projects from the U.K. and different countries in the world will be described and discussed in the article and presentation.

I. INTRODUCTION

Technology around monitoring solutions evolved dramatically in the past decade. Modern telecommunications solutions, cloud computing power and measurements digitalization have changed completely the way we are allowed today to approach monitoring challenges today. The purpose of the paper has been to investigate the benefits and limitations of some of the latest innovations for structural monitoring.

A monitoring solution is requested to deliver information to an end user in order to allow him to take better decisions. This simple statement has been driving monitoring solutions development more and more towards fully automated process, able not only to collect accurate data but to validate the measurements, combine, filter and simplify the results up to a clear green or red light in some cases.

This is one of the reasons why one of the key processes happened in the last few years has been the democratization of monitoring solutions.

The complexity of a solution that needs to integrate accurate sensors, power supply and telecommunications systems with software interfaces has been dramatically reduced by the latest technological innovations.

Almost power free systems (10+ years of autonomy) are now commonly used and millions of points coordinates of a laser scanning system are reduced to powerful colormaps and statistics in real time.

These are only 2 examples of solutions there were not available only a few years ago.

In the past sensor best technology and highest accuracy were the main focus while nowadays reliability is key because it is functional to a fully automated data acquisition workflow; and automation intelligence is required as well as telecommunications and programming skills.

5G networks, IoT interfaces and BIM adoptions in constructions are again pushing more in the direction of the future monitoring systems.

The technology is changing fast, and winning monitoring solutions will have to follow.

II. ROBOTIC TOTAL STATIONS & MONITORING

Robotic Total Stations have been used in monitoring for a long time. The great benefit is the possibility to measure with millimeter-level accuracy a great number of points from a single installation. Applying well-known surveying principle the solution can be made reliable and the total stations can be controlled automatically measuring a network of control points to determine and monitor the precise location and orientation of the instrument.

Since 2011 robotic total stations designed and produced specifically for monitoring applications like the Leica TM30 series have been available in the market, showing scope for a dedicated development of the technology for monitoring purposes.

Figure 1. Leica TM30 in action on a metro project

Another benefit of using a robotic total station is the reflector less mode that allows measurements, although less accurate, without the need to install targets or prisms on the structure. This makes the method not invasive and allows emergency actions as in the case of the Costa Concordia disaster.

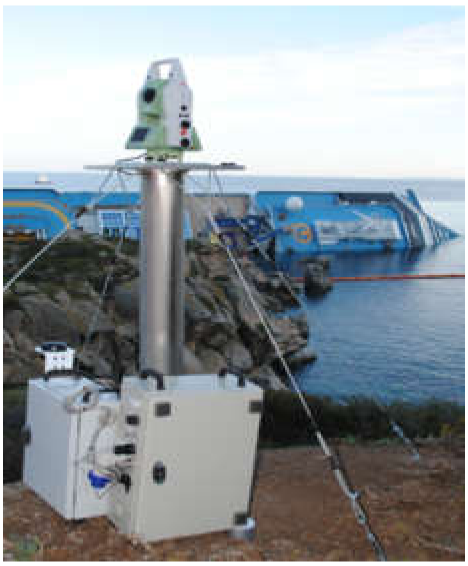

Figure 2. Leica TM30 installation at the Costa Concordia

The latest innovations have pushed monitoring total stations developments towards more reliable instruments, capable to be trusted for 24/7 operations in any conditions.

The Leica TM50, introduced in 2015, matches the military standard MIL-STD-810G method 506.5-I for dust and water (rain) resistance and shows an extended operative temperature range of -20 to +5- degrees.

Figure 3. Total station in challenging monitoring conditions

III. Automated Imaging

One of the most important new features of modern robotic total stations is imaging. Advancements in technology, mainly digital cameras and telecommunications allow the integration of high-resolution cameras into robotic total stations. This means, effectively, to have a web cam, fully automated and remotely controlled, combined with the total station and therefore always able to be precisely orientated towards the desired target.

Adoption of imaging total stations for monitoring purposes have seen a constant growth since their launch to the point that they have overtaken the number the non-imaging units in the UK market in 2017.

Automated imaging allows the operator to “see” what the instrument is looking at and to drive the instrument based on that information updating the coming images.

The camera or multiple cameras on board can provide automatically or on-demand visual footage from the monitoring site; in other words, automatic imaging opens the opportunity to “have a look” at something on site.

Imagine a scenario where the results of a monitoring system start to trigger alerts levels. After the first checks that the system is fully operational and that the data are validated, a very common action is precisely to “go and have a look”, check what is going on. Automated imaging allows remotely, on demand or automatically, to get immediate information about the site conditions, the status of a target and spot, for example, the presence of an obstruction.

In a lot of cases the use of remote imaging saves a site visit.

Figure 4. Picture of Prisms on railway from a total station

Sometimes the robotic total station is installed in remote or difficult to access location from where could be time consuming or even dangerous to set up the system. Using automated imaging features it is possible to remotely perform the point learning and set up routines in more safe and faster way.

Figure 5. Difficult set up installation.

At last, using the possibility to take pictures very accurately, it is possible to use automated imaging to get visual documentation of specific details, as, for example, a crack.

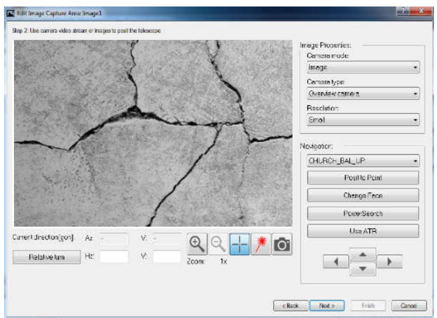

Figure 6. Leica GeoMoS capturing a crack

IV. AUTOMATED SCANNING

Laser scanning is a consolidated surveying technique but only in the last 3-5 years it started to be considered as valid monitoring solutions.

Laser scanning monitoring is based on surface to surface comparisons rather than point to point and the results (movements) are displayed as colormaps.

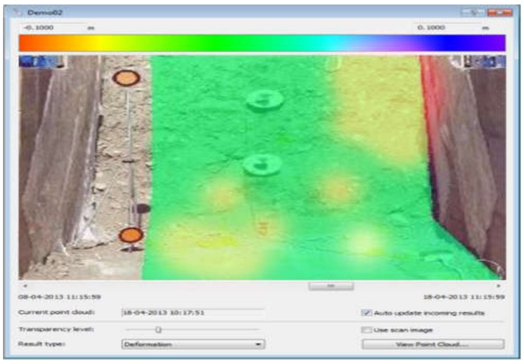

Figure 6. Leica GeoMoS surface colormap

The n.Vec technology adopted by Leica Geosystems provides automatic scan cloud processing to deliver real-time deformation information. The main benefits are clearly the details level of information without the need for access to the monitoring subject which is monitored in a complete not intrusive way.

The n.Vec algorithm is able to compute displacements in the direction orthogonal to the monitored surface, this makes complicated setting alarm thresholds based on large scan areas where multiple "orthogonal" directions are involved.
The methodology of patch scanning solved this problem reducing the scan area to little patches- generally not bigger than 0.5 square meter – with a defined orthogonal direction. The methodology allows to set alerts and alarms, to get quick information and to have a much simpler interpretation of the results.

The methodology is now the most common automated scanning solution worldwide and has been adopted even in the monitoring scheme during the enabling works at HS2 in London.

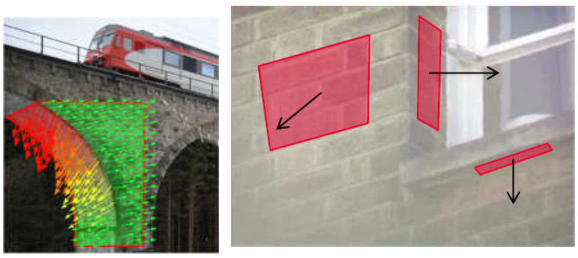

Figure 7. multidirectional colormap VS Patch scanning

The focus of the paper study has been to test in challenging conditions (wet and busy surfaces) the accuracy performances of the system. The setting has been a monitoring system in Dublin on the tram track on a road kept open to traffic.

Automated scanning Case Study

The need for student accommodation has grown exponentially in Dublin over the years. The recent development of the Grangegorman University will have a student population of around 28,500. A shortage of beds has seen developers invest at key areas around the city.

The commercial buildings on Dominick Street Upper was run down and derelict. These were purchased to facilitate the accommodation shortfall in the North Dublin area.

The goal was meet design requirements, local council regulations and TII's code of practice.

The monitoring solution had to ensure the effectiveness and reliability of the alarm protocol. To provide a means of accurate notifications to all the project management team.

No. 2 Leica MS60 multi stations connected to a remote GeoMoS Control center have been used to control vertical movements of the track.

System requirements were 24/7 operation with millimeter-level accuracy.

Manual crosscheck measurements have been done using precise digital levelling.

Environmental monitoring has been integrated as well.

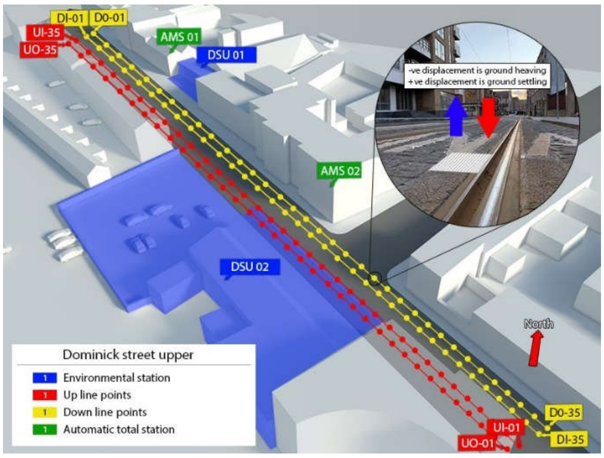

Figure 8. monitoring scheme

Results have been above expectation showing an average standard deviation in the measurement of less than 1 mm in the majority of the scanned areas.
Few scan areas results over a month are shown below:

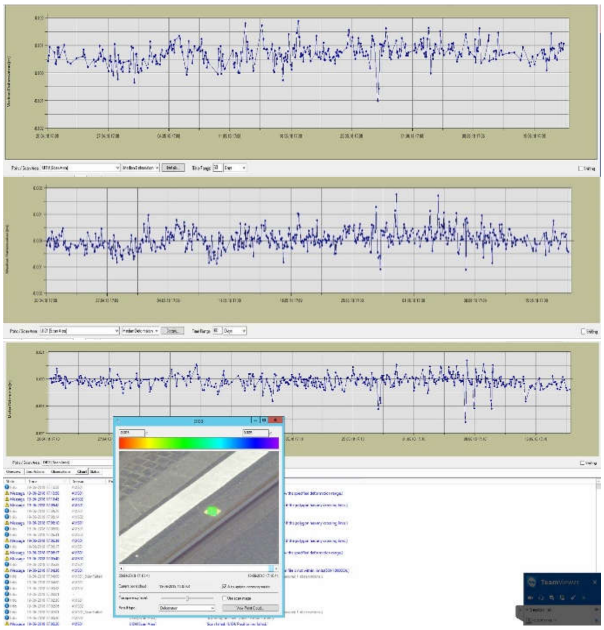

Figure 9. Dublin scanning results

The results are presented as the median deformation or the median value of the displacements recorded across a specific scanned patch.

The results are computed in real time thanks to modern processors and the advanced algorithms.

It is nowadays possible to compute different statistics out of a point cloud to point cloud solution as the

- Median deformation
- Maximum deformation
- Volume deformation

The monitoring results, over an extended period of time (over 6 months), show similar accuracy levels expected by prism installation.

The same workflow, on periodic monitoring schemes, has been adopted for the HS2 enabling works in London.

Figure 10. Dublin scanning results

V. Wireless Mesh Technology

IoT revolution has now arrived in the monitoring world as well and one of the best examples are wireless mesh networks of geotechnical sensors.

Adopting Low Power High Range Wireless solutions, geotechnical sensors are capable to establish wireless mesh networks to reach a gateway to the internet.

The network is formed and configured automatically and it is able to adapt to changes in the line of sight between the sensors.

The network is designed to be extremely power efficient and the solution developed by Wisen is able to last for 10+ years on small rechargeable batteries.

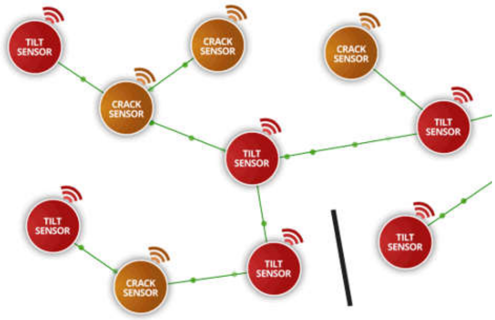

Figure 11. Mesh network

The monitoring system is now an example of intranet of things where the components are able to manage the comms and power consumption challenges thanks to their capacity to talk one another.

The network is always optimizing the data traffic and therefore it is maximizing power efficiency at the same time.

Any 4-20 mA, vibrating wire, laser distometer and tiltmeters sensors can be connected.

The solution found a wide number of applications in the monitoring environment.

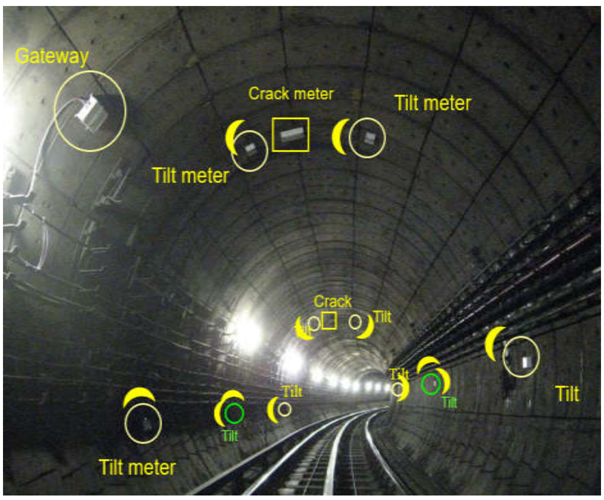

Figure 12. Mesh network

The biggest benefit of the solution is that it is extremely easy and fast to install and operate.

Figure 13. Prism and Tilt on the same Railway

Comparing results on cant and twist computation for railway sites the systems have produced the same level of accuracy.

The Wisen solution tested allows full real-time control over the sensors and settings.

VI. Conclusions

Many improvements in the technological world had a great impact on the way we do monitoring.
Computation, communications and storage capability are only a few examples of what made automated imaging, scanning and wireless IoT monitoring network a reality.
Many more improvements deserved to be included in this paper, for example, the real-time least square adjustment process of thousands of measurements offering the best possible result to the final user or integrated cloud computing.

Monitoring is about accuracy, which is again a measure of how the error is distributed around the right value of a specific unknown; modern systems can now tell us much more about how close we are to a good measurement thanks to new techniques and algorithms that allows new ways to do monitoring.

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