

3-DEMON MONITORING PLATFORM: EXAMPLES OF APPLICATIONS IN STRUCTURAL AND GEOTECHNICAL MONITORING PROJECTS

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Abstract: The 3DeMoN (3-Dimensional Deformation Monitoring Network) monitoring platform integrates conventional monitoring devices and sensors (e.g. GPS receivers, Laser distance meters, Dataloggers, etc.) with lowest power semiconductors, wireless communication, advanced database systems and Internet, with the aim to provide a unified management and view of remote monitoring data. The open hardware and software architecture of the system allows expanding its applicability to many domains, requiring the remote management of a network of different data acquisition devices. This contribution presents the monitoring platform as well as some relevant monitoring projects where the 3DeMoN system was successfully applied. In particular landslide monitoring applications as well as roof deflection monitoring in buildings using the 3DeMoN-ROBOVEC solution will be presented.

1. INTRODUCTION TO THE 3DEMON MONITORING PLATFORM

The 3DeMoN system can be defined as an autonomous and automatic monitoring system consisting of a number of so called Monitoring Stations distributed on the object to be monitored (e.g. a landslide, a bridge or a building) and connected to one or more digital (e.g. GPS receivers or laser distance meters) or analogue sensors (e.g. inclinometers, load cells, etc.) and a so called Central Server Station (CSS).

A 3DeMoN Monitoring Station consists of a weatherproof box containing the electronic components for the management of the sensors, the data transmission and the power supply modules. The Monitoring Stations communicate with the Central Server Station through a wired connection (RS-232/485, fiber optic) or through a wireless connection (GSM/GPRS/EDGE, radio modem). The Central Server Station provides for data collection, data storage, management of the configuration of the Monitoring Stations, automatic data processing (e.g. automating batch post-processing of GPS data) and monitoring of the correct operation of the network.

Figure 1 shows the architecture of the 3DeMoN monitoring platform.

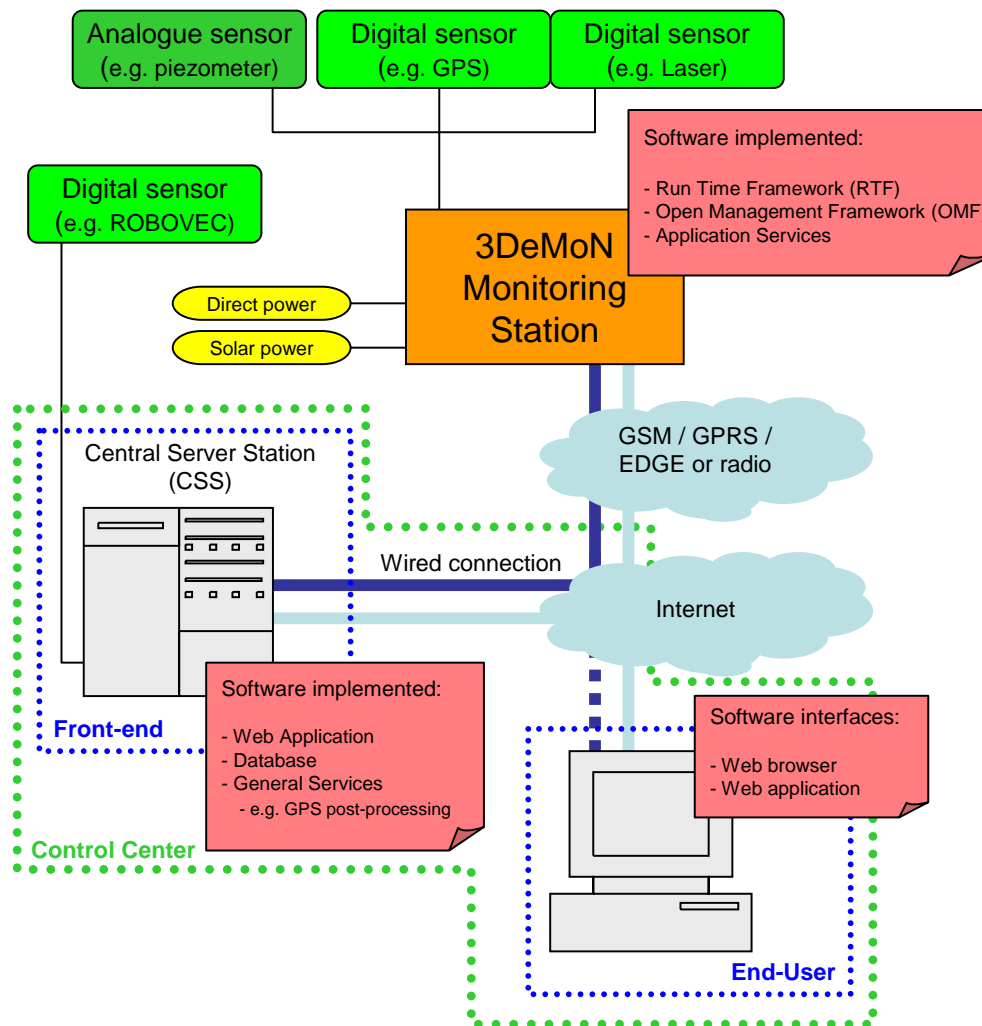


Figure 1: 3DeMoN monitoring platform architecture

2. THE 3DEMON CONTROL CENTRE SOFTWARE

The 3DeMoN Control Centre software is an integral part of the monitoring system and consists of all the software modules running on both Front-End and End-User levels (see Figure 1). Its development started to respond to the market's lack of flexible, scalable and robust software solutions to manage an extensive and heterogeneous network of measurement devices. In today's environmental and structural monitoring projects the information collected by conventional sensors, usually controlled by local data-loggers, is complemented or replaced by data acquired with more complex instruments like e.g. GPS receivers or Laser distance-meters. These devices are controlled by a more extensive set of parameters and the returned measurement data needs in some cases to be post-processed applying instrument specific algorithms or transformations.

The 3DeMoN Control Centre is a generic framework responsible for managing the configurations of the 3DeMoN remote Monitoring Stations and the single sensors or

instruments connected to them, to establish manual or automatic connections to the stations, to remotely (re)configure the entire system, to download and locally store the measurement data, to trigger automatic post-processing and analysis activities on the collected data, to generate warnings and to publish results in different formats.

The architecture of the 3DeMoN Control Centre is based on a modern object- and component-oriented design and is implemented with the Java™ programming language, conforming to the Java™ 2 Enterprise Edition (J2EE) standards. The basic framework of the application can be extended, according to requirements of each single monitoring project, by pluggable software components specific for a certain communication device and protocol (e.g. GSM/GPRS/EDGE, Radio, RS-485 bus, etc.) or measurement instrument.

3. THE 3DEMON-GPS SYSTEM

The first measuring device that was integrated in the 3DeMoN platform was a single frequency L1 GPS receiver. This allows setting up one or more autonomous GPS rover measuring stations on the object to be monitored (e.g. a landslide, a building, etc.) plus one or more GPS reference stations. The reference stations are to be located at stable locations and outside the monitored and moving area. The carrier phase data from the GPS satellites are synchronously collected by all measuring stations of the network and automatically uploaded on the Central Server Station.

Finally an automatic GPS static post-processing service performs all needed conversions, re-sampling and baseline calculations, returning the relative 3D coordinates of the monitored points as the final result of each measuring campaign. The system is able to run the full data acquisition, data transmission and data post processing automatically



Figure 2: 3DeMoN-GPS rover measurement station with solar power supply

3.1. Performance and accuracy

The performance of the system is summarized in the following table:

Maximal baseline length	15 Km
Typical acquisition time	20 min
Typical acquisition rate	0.1 Hz
Accuracy of raw data:	X, Y coordinate: $\pm 4\text{mm}$ Z coordinate: $\pm 9\text{mm}$
Accuracy of statistically analyzed data:	X, Y coordinate: $\pm 2\text{mm}$ Z coordinate: $\pm 4\text{mm}$

Table 1: Performance of the 3DeMoN-GPS system

4. THE 3DEMON-LASER SYSTEM

The 3DeMoN-Laser is a laser distance meter based system that allows performing continuous and autonomous millimetre scale distance measurements for distances up to approximately 1,000 m.

A typical remote 3DeMoN-Laser system configuration consists of a DeMoN Monitoring Station managing up to 3 laser instruments. In case of outdoors installations the laser instruments are usually mounted into a protection cabinet (see Figure 3).

When directly connected to the CSS, e.g. in case of a local monitoring system inside a building, up to 160 laser instruments can be integrated in the same network, combining RS-422 bus and Ethernet connections.

The 3DeMoN-Laser system can be applied in several surveying applications such as landslides, earth settlement, slope instability, tunnel monitoring, tank level monitoring or civil engineering surveying, where millimetre-scale distance measurements are to be performed.



Figure 3: Installation with two 3DeMoN-Laser instruments and a 3DeMoN Monitoring Station with solar power supply

The performance of the system is summarized in the following table:

Maximal measurable distance	~1,000 m
Typical measurement time	0.2 – 4 s
Maximal acquisition time in tracking mode	6 Hz
Typical accuracy (standard deviation)	±0.2 mm (indoor measurements) ±1.5 mm (outdoor measurements)
Target needed	up to ~50m: none up to ~200m: reflecting surface up to ~1 km: geodetic prism

Table 2: Performance of the 3DeMoN-Laser system

5. THE 3DEMON-ROBOVEC SYSTEM



Figure 4: ROBOVEC instrument

The ROBOVEC unit is based on a laser distance meter mounted on a bi-axial modular robotization for horizontal and vertical orientation of the measuring device. The instrument is able to measure the variation of distances and the variation of horizontal and vertical angles. Additionally, temperature and strength of reflected signal are acquired and stored during every measurement.

The instrument is managed through an Ethernet connection and can therefore be easily integrated into existing monitoring systems through wired or wireless LAN.

Typical accuracy for distance	± 1.5 mm outdoors ± 0.2 mm indoors
Maximal measurable distance	$\sim 1,000$ m
Distance resolution	0.1 mm
Angle measurement resolution	0.0013°
Measuring sampling rate (tracking mode)	6 Hz
Laser spot diameter (at distance)	8/25/40 mm (10/50/100 m)

Table 3: Performance of the 3DeMoN-ROBOVEC system

During a measurement task, the ROBOVEC can perform a full scan of the reflected signal strengths on selected targets. The acquired data are then automatically processed by the software using proprietary centre-finder algorithms. These allows calculating the new target's centre coordinates and following moving targets (e.g. on a landslide) in the long-term.

Figure 5 shows a typical image of the reflected signal strength with the results of the centre-finder algorithm.

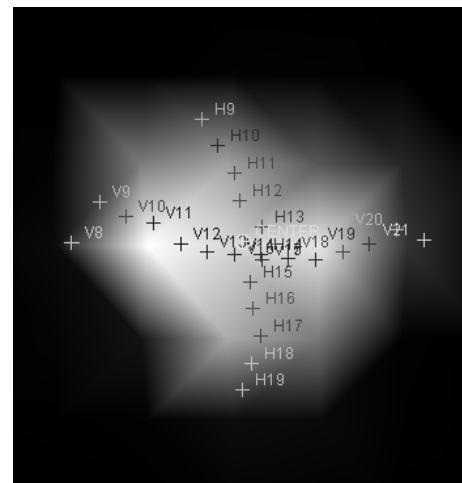


Figure 5: Typical centre-finder algorithm result

An important characteristic of the ROBOVEC is that this instrument does not need to be levelled and can therefore also be installed vertically (e.g. on a wall) or, if necessary, even upside down.

Since for distances shorter than ~50m (depending on the on-site conditions) no reflecting target is needed, besides the typical surveying and monitoring activities the ROBOVEC can also be used for other purposes such as e.g. the acquisition of profiles or scanning of surfaces.

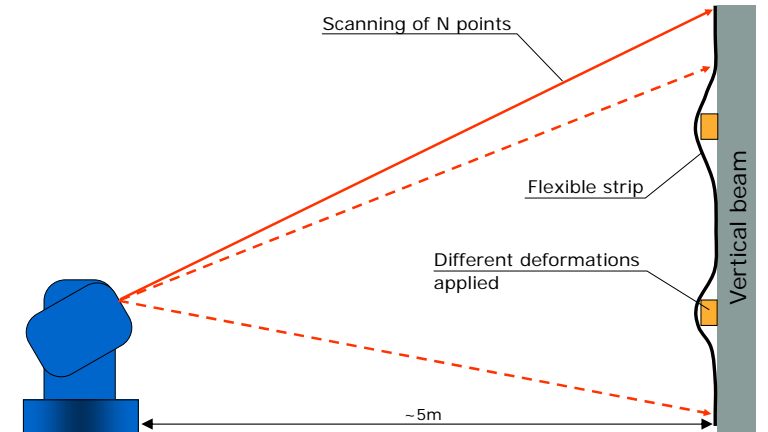


Figure 6: Test configuration for profiles acquisition using ROBOVEC

Figures 6 and 7 show the setup and results of some profile acquisition tests performed on a vertical beam at a distance of approximately 5m.

A total of 16 points were measured along the beam.

The typical acquisition time for each test was ~2 minutes with an accuracy of 0.6 mm (2σ).

The results show a very accurate and reliable response of the instrument and confirm that it can be successfully applied for such profiling applications.

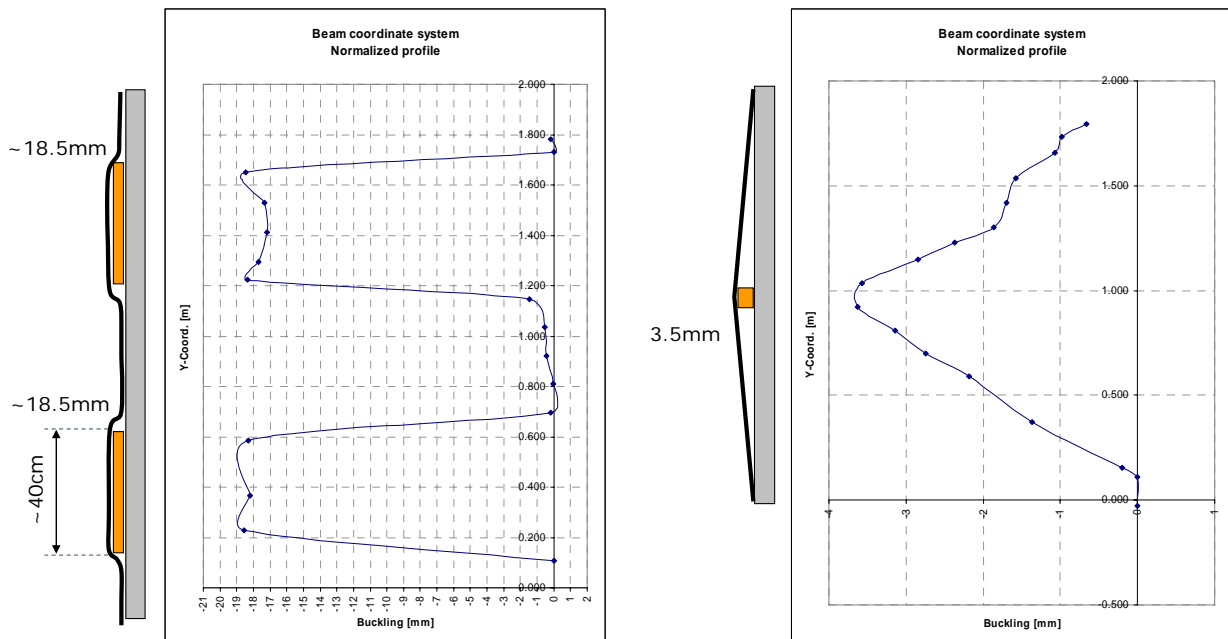


Figure 7: Results of vertical profiles tests

6. CASE STUDY: LANDSLIDE MONITORING



Figure 8: ROBOVEC installed on a pillar

A ROBOVEC unit was installed in June 2006 on the "La Frasse" landslide in the Vaud canton, Switzerland, not far from the city of Lausanne. The landslide involves ~40 Mio m³ of material and its width varies between 500 m and 1,000 m. This landslide is considered one of the most important and active landslides of the Alps, with average displacements of 30-50 cm/year.

A total of 16 points (14 on the landslide plus 2 reference points outside the sliding area) were equipped with geodetic prisms and are measured every 2 hour. This landslide is also instrumented with 4 inclinometers. These are manually measured every 2 months. As shown in Figure 8, the instrument was installed on a concrete pillar on the opposite side of the valley. The measured distances vary between 110m (Reference 2) and 660m (Reference 1).

The PC managing the ROBOVEC is equipped with a WiFi / GPRS / EDGE card, allowing a real-time and high-speed remote access to the measurements. A direct connection to the 220 VAC power supply is available on-site.

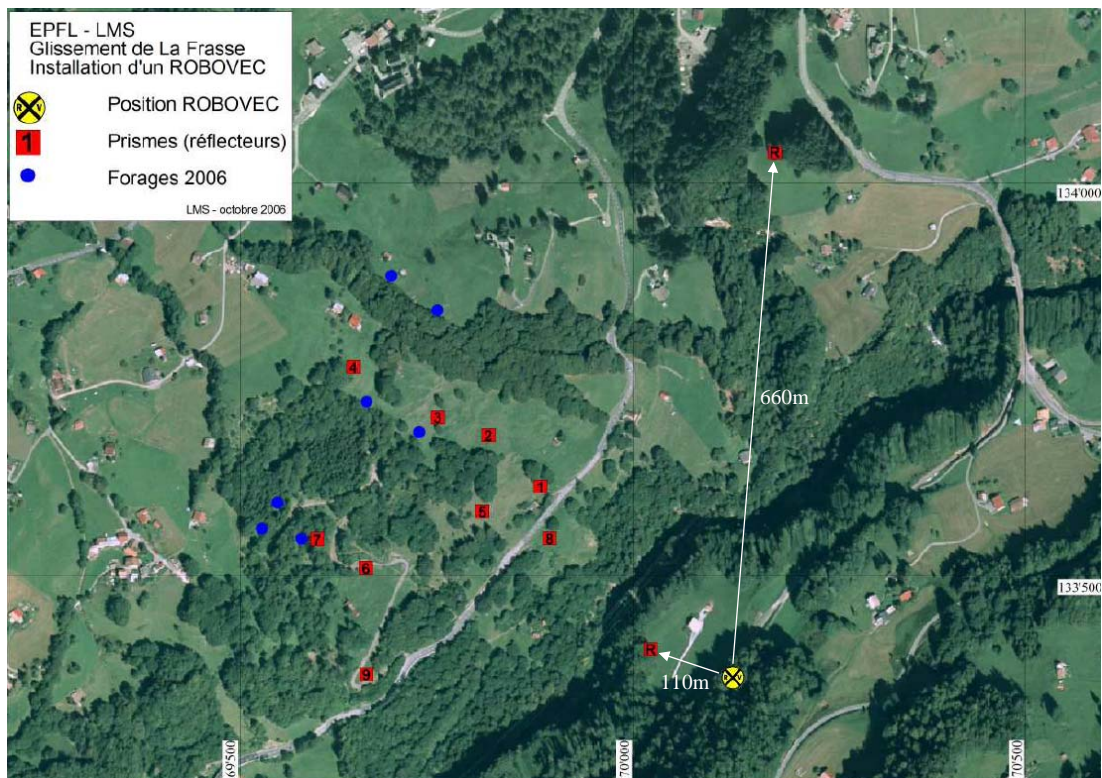


Figure 9: Overview of the landslide, with targets (1-9) and reference points positions

Figure 10 shows the reactivation of the landslide in November 2007. The last important sliding event occurred during winter 1993-94, with a total displacement of 3.5 m for this year and maximal sliding speeds of 1 cm/day.

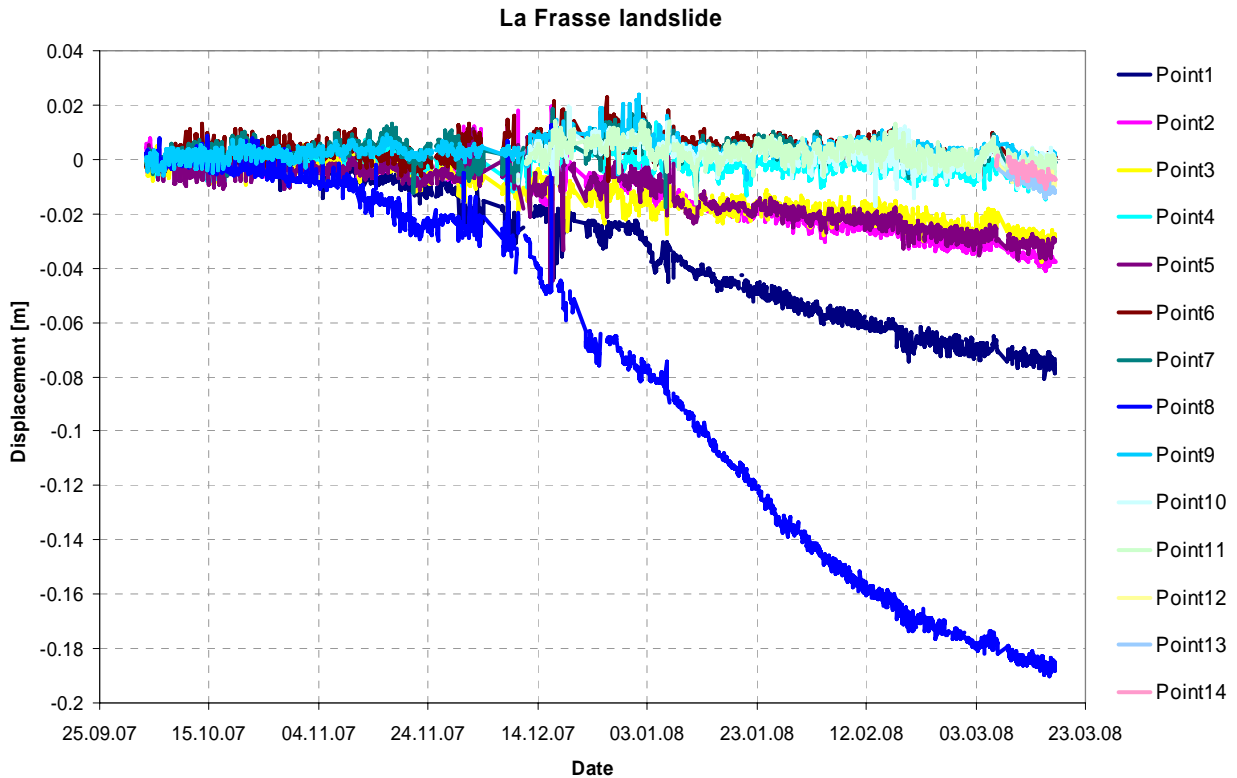


Figure 10: Landslide reactivation in November 2007

Figures below show the influence of changing temperature on the measured distance for the furthest point (Reference 1 at ~660m distance). The liner correlation between these two parameters allows applying so called meteo-corrections on the distance measurements.

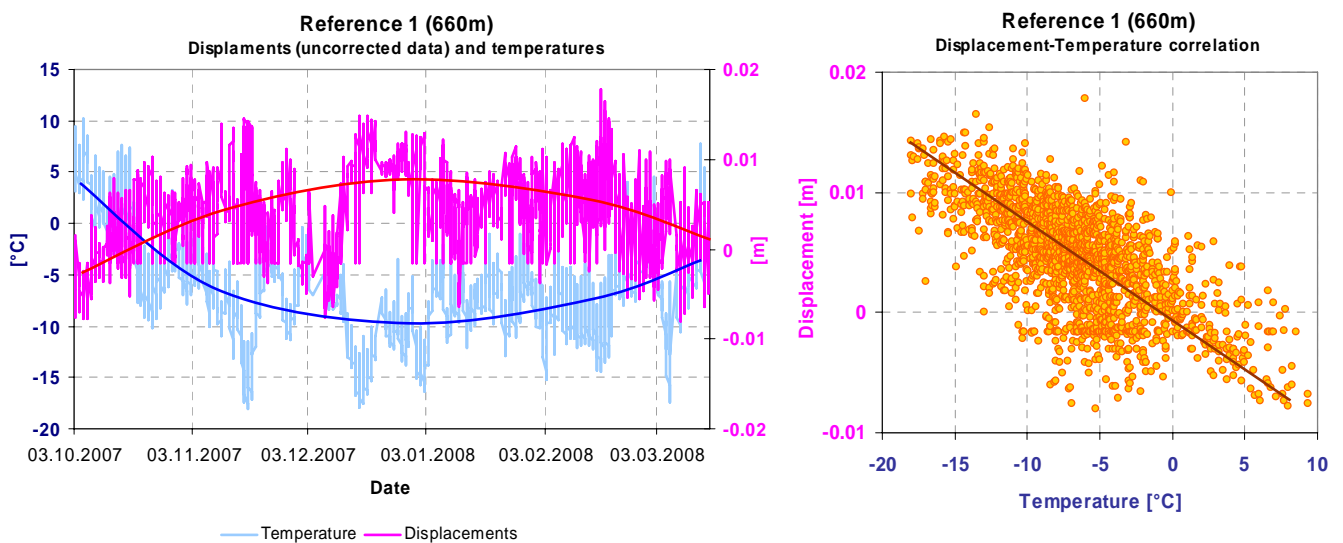


Figure 11: Influence of the temperature on distance measurements

7. CASE STUDY: ROOF DEFLECTION MONITORING

The Halifax Metro Centre is a multi-entertainment, sports facility and exhibition centre connected to the World Trade and Convention Centre. It is the largest arena in Halifax and is host to a range of entertainment and sporting events in the city. It currently has a seating capacity of 10,595 for ice hockey. Since the arena's construction in the late 1970s, the design loads have increased substantially and there is an ever increasing use of suspended equipment for lights and sound for special events, increasing the entertainment loads.



Figure 12: The Metro Centre arena in Halifax

The owners of Halifax Metro Centre decided to conduct a structural investigation of the roof structure and provide means to effectively monitor the actual snow loads and manage the entertainment loads suspended from the roof. Based on the research, a complete Structural Health Monitoring System combining fibre-optics based sensors and a ROBOVEC unit was installed and provides real time information on the status of the roof structure

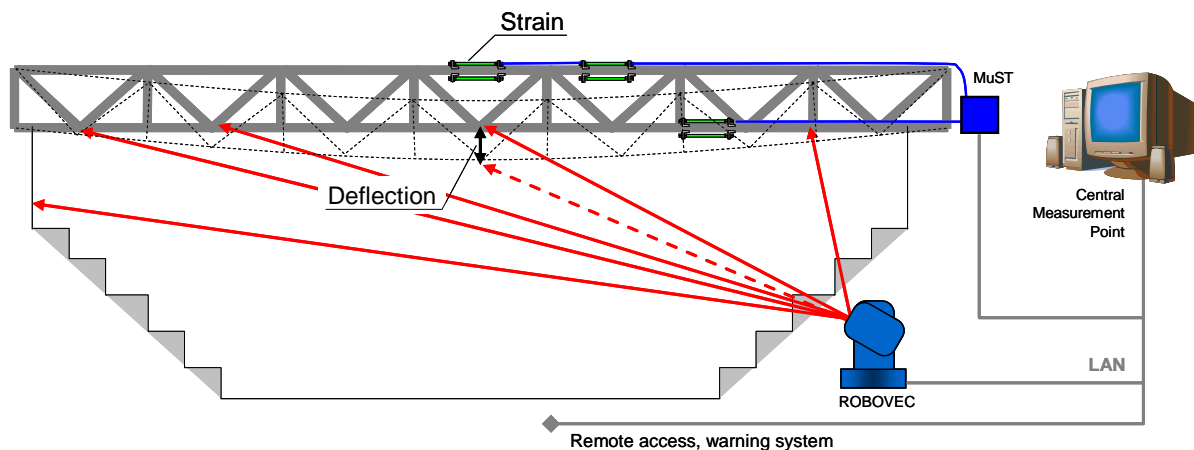


Figure 13: System configuration

Both Reading Unit for the fibre optic sensors and ROBOVEC instrument are connected to the existing LAN and a dedicated PC manages the sensors, the data acquisitions and the measurements. The strain data of the fibre optic sensors are automatically compensated using the corresponding temperature sensors, while the laser angle and distance measurements are automatically transformed in a deflection value. Warning and alarms are dynamically generated when pre-defined strain thresholds in the beams or deflection thresholds of the trusses are measured. These events are notified via email to a certain number of persons of the security staff of the building, as well as notified in form of a warning light in the control room.

Figure 14 shows the deflections measured with the ROBOVEC during a period of 2 weeks. The instrument performs a full scans of all the targets every 6 hours, while the 36 fibre optic sensors are scanned every 15 minutes.

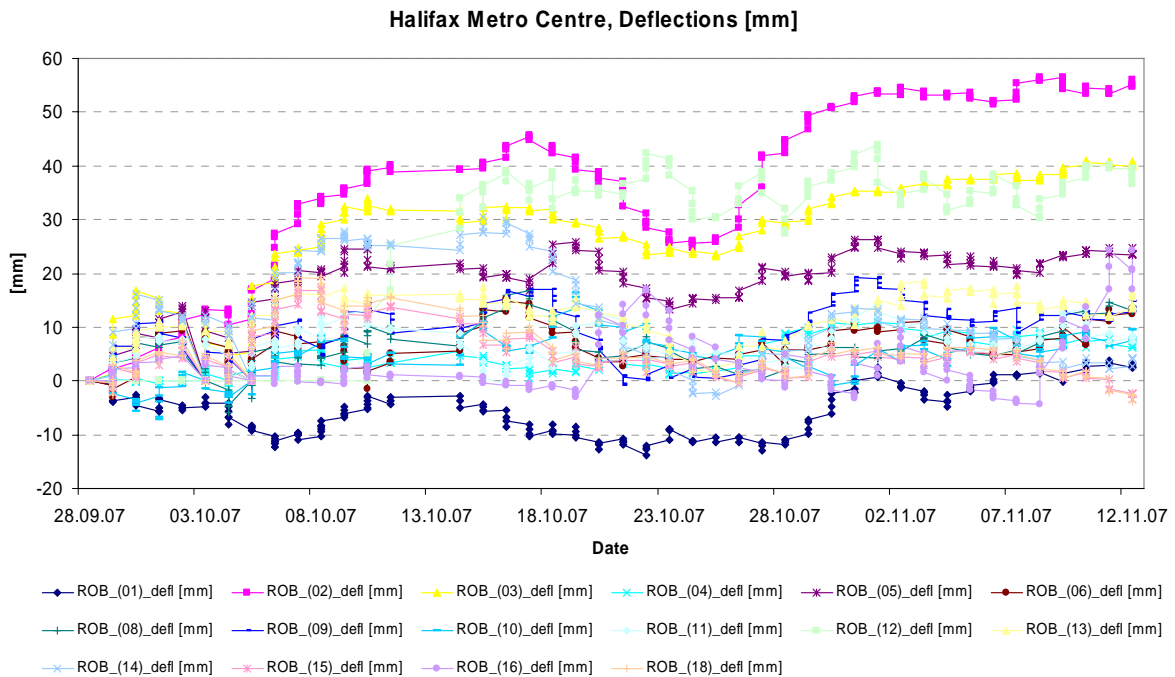


Figure 14: Snapshot of measured deflections



Figure 15: ROBOVEC installed on a column at the Metro Centre



Figure 16: Central Measurement Point with dedicated PC (left) and Fiber Optic reading unit with switch (right)

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