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Bridge health monitoring system

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ABSTRACT: Generally visual inspection is done for bridge health monitoring. This might be suitable for monitoring the structurally sufficient for noncritical structures. But it is not reliable when it comes to monitoring actual health of structures. Remote monitoring of structures using sensors provide accurate results and up-to date data which allows to assess the integrity of a structure. Modern development on sensing, communication and storage technologies have also enabled the use of broad-scale Structural Health Monitoring (SHM) system to the infrastructures. Scientist have developed way to implement technology on infrastructures health monitoring system. Wireless Sensor Network system (WSNs) and Wireless Smart Sensor Network system (WSSNs) have been studied and applied to replace traditional wired sensor system for monitoring structural health. Bridge Health Monitoring System for Paira Bridge will also use this modern technology.

1 INTRODUCTION

A most critical part in every transportation network is Bridge. They are always expensive projects and any failure of the projects has the ability of make a serious disaster. Therefore, health monitoring of bridges always holds great significance. For a proper investigation of estimating the remaining lifetime of the structure, the current stage of the structure is not enough. Detailed knowledge on the deterioration pattern with future stresses is needed for factual monitoring.

Bridge Health Monitoring System (BHMS) is an important component of Structural Health Monitoring System (SHMS). A Structural Health Monitoring System is an assembly of sophisticated electronic devices installed on civil engineering structures with the purpose of assessing the actual condition of the structure. The main focus of structural health monitoring is to gather all behavioral data of in-service condition of the structure along with real time and continuous assessment.

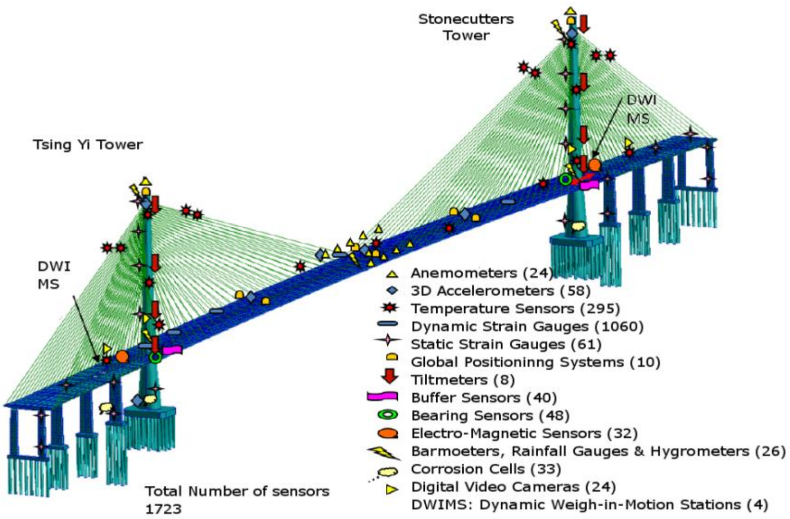

Figure 1. Bridge health monitoring system.

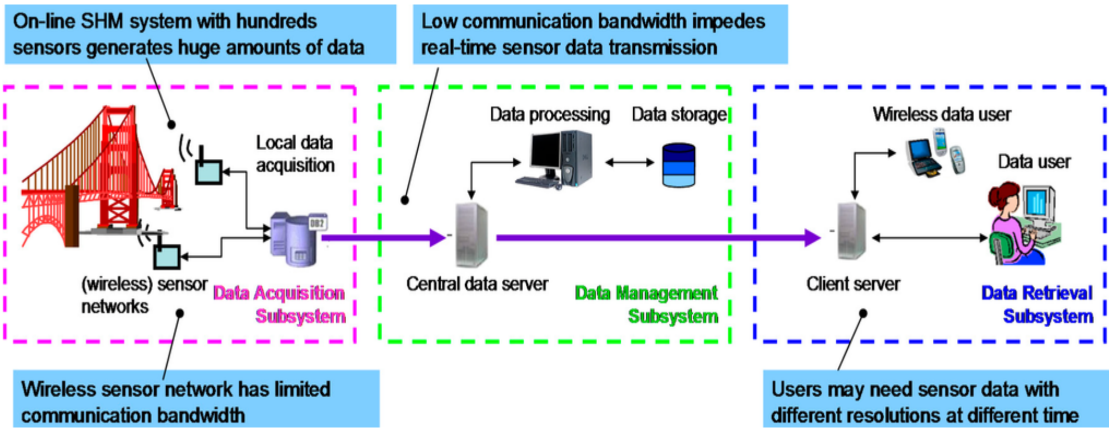

Figure 2. Bridge health monitoring system flowchart.

2 TYPES OF BHMS

2.1 *Visual Inspection*

Traditionally visual inspection is the most common way of monitoring structures. According to the standards set by the FHWA of USA, every bridge is required to undergo a visual inspection once every 2 years. However, this might be suitable for monitoring the structurally sufficient noncritical structures but not reliable when it comes to monitoring actual health of structures. Disadvantages of visual inspection:

– Scheduled maintenance and periodic inspections offer only specific information of structural condition.
– Costly in terms of extensive labor and downtime.
– Due to experiential dependence, traffic disturbance and high-cost regular visual inspection does not reflect the true performance state of bridge components accurately.

2.2 *Wired Structural Health Monitoring System*

A traditional wired SHM system included three major components: a sensor system, a data processing system and a health evaluation system. The data of the sensor system are processed intensively by the data processing system after being transmitted through coaxial wires. Disadvantages of wired SHMS:

– High cost, low efficiency, susceptible disturbance, inflexibility.
– Changing or addition of new sensors required extra cables for data transmission and also renewal of data management software.
– After completion of the wired SHM system, further modification of the sensor system resulted a lot of auxiliary works.

2.3 *Wireless Sensor Network System (WSNs)*

The high cost associated with the installation of wired sensors can be greatly reduced by employing wireless sensors. The new advances of micro electro-mechanical systems (MEMS), wireless sensing technology and integrated circuit technology help to introduce low-cost wireless sensors with onboard computation and wireless communication capabilities. The WSNs-based bridge health monitoring system is consisting of hardware and software. The hardware is usually comprised of a wireless sensor and central server. The software consists of several components such as network operation, data collecting, data processing, power management, and so forth.

In general, a wireless sensor is composed by four functional subsystems: a sensing interface, a computing core, a wireless transceiver, and a power source. However, influencing factors include- type of the structure to monitor, sensor locations, environmental aspect of the structure. Several types of wireless sensors need to be installed on key locations on a bridge. The central server sends commands to activate wireless sensors, establish a WSN and set the monitoring parameters in the beginning; then, the whole WSNs executes time synchronization; after that, the wireless sensors begin collecting data and transmitting raw data or processed results back to the central server. The measured data then can be employed for advanced structural performance evaluation. Advantages of wireless sensor network system (WSNs):

- This system eliminates the high cost of cable, depending on the data transmission.
- The installation of wireless sensors is very easy without deploying complicated cables.
- As the sensors are organized by wireless transmission, after the initial installation updating, adding moving and replacing of sensor is easy.
- During the original data acquirement operation, the network reorganizing can be done quickly without disturbance.

Disadvantages of wireless sensor network system (WSNs): Large amount of data generated by a monitoring system.

2.4 *Wireless Smart Sensor Network System (WSSNs)*

To deal with the large amount of data generated by a monitoring system, on-board processing at the sensor allows a fraction of the computation to be done locally on the sensor's embedded microprocessor. Smart sensors provide such an approach with abilities to self- diagnosis and self-calibration capabilities which reduces that amount of information needs to be transmitted over the network. Smart sensor is divided into three parts (i) the sensing element (ii) signal conditioning and (iii) a microprocessor. The feature that distinguishes smart sensor from a standard integrated sensor is its intelligence capabilities. Smart sensors are capable of decision-making in case of storing/dumping data. A well-developed smart sensor platform (Imote2) is released for application in SHM of Civil Infrastructure.
Advantages of WSSNs:

- This sensor can enable self-diagnostics, self-identification or self-adaptation functions.
- It can also minimize power assumption by controlling when and how long will the sensor fully awake.

Disadvantages of WSSNs:

- The lack of adequate resources on smart sensors.
- In case of hardware, smart sensors are usually battery powered with limited RAM and has relatively slow communication speed.
- Smart sensors may have intrinsic synchronization error and communication among sensors can be erratic.

3 DIFFERENT COMPONENT OF BHMS

3.1 *Measurement Devices (Sensors)*

Sensors are installed directly on the structural elements, they measure physical parameters and transfer the information as a digital or analog signal.

3.2 *Cables / Radio Waves*

Means for transmitting the signals from the sensors to the acquisition units.

3.3 *A/D Converters, Signal Conditioners, Filters*

Electronic devices transforming the analog signals to digital information. Signal amplifiers and Conditioners a reused to amplify very small ambient signals, thus enabling a reliable evaluation.

3.4 *Data Acquisition Unit*

A data-logger that receives all the signals measured by the sensors. This is accompanied by an industrial PC equipped with large hard disks since large amounts of measuring data have to be processed.

3.5 *Data Processing Software*

Specifically designed software is capable of data management and remote control of the system.

3.6 *Internet Router*

Network connection enables data transfer to end users. This enables also the possibility to receive alarms and notifications anytime from the system.

4 ADVANTAGES OF BHMS

4.1 *For Owners & Authorities*

- Improved understanding of in-situ structural behavior.
- Early damage detection
- Assurances of a structure's strength and serviceability
- Reduction in down time
- Improved maintenance and management strategies for better allocation of resources.
- Enhanced safety of overall structure and its critical elements
- Risk minimization by Safety Monitoring
- Increased lifespan of structure and reduction of lifecycle costs
- Optimization of maintenance activities
- Efficient support for structure inspection department
- Risk management: Properly defined and measurable risks

4.2 *For Designers & Engineers*

- Verification of designed / expected structural performance
- Confirmation of design parameters
- Model updating to optimize design cal-culations
- Increase of design experience and tech-nical excellence

4.3 *For Construction Companies*

- Proof of properly executed construction work
- Optimization of construction processes

5 DISADVANTAGES OF BHMS

- The only disadvantage is that the sensors may fail when there is an adverse condition.
- So there must be a system incorporated which will detect sensor failure.

6 SOME COMMON SENSOR/DEVICE USED IN BHMS

6.1 *Displacement Sensor*

Measure longitudinal movements of different point of the bridge. Example of use: at the expansion joints.

6.2 *Tilt Meter*

Measure the verticality or inclinations. Example of use: inclination of the pylons.

6.3 *GPS*

Measure movement of different component of bridge. Example of use: movement of deck slab, pylon etc.

Figure 3. Ultrasonic displacement sensor.

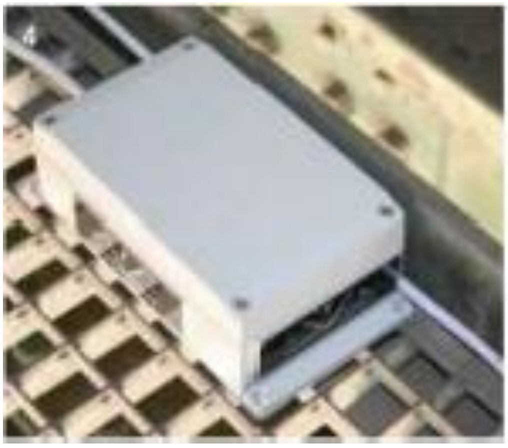

Figure 4. Tilt sensor.

Figure 5. GPS position sensor.

Figure 6. Weather station.

Figure 7. 3D acceleration sensor.

Figure 8. Strain gauge.

6.4 *Weather Station*

Measure environmental parameters which affect the behavior of the structure. Example: wind speed and direction for vibration of deck and cables, air temperature for longitudinal movement at the joints.

6.5 *Accelerometer*

Uniaxial, biaxial accelerometer can measure the amplitude of structural vibrations under wind action and dynamic traffic loads. Detection of natural frequencies of bending and torsional behavior for dynamic characterization of the structure. Example of use: in deck, pylon, cable etc.

6.6 *Strain Gauge*

Strain in steel element measured by strain gauge devices, incremental changes are measured at the surfaces, analyze stress and fatigue.

6.7 *Temperature Sensor*

Measure temperature of different component under different condition.

Figure 9. Temperature measurement.

Figure 10. Vibration measurement.

Figure 11. Corrosion monitoring.

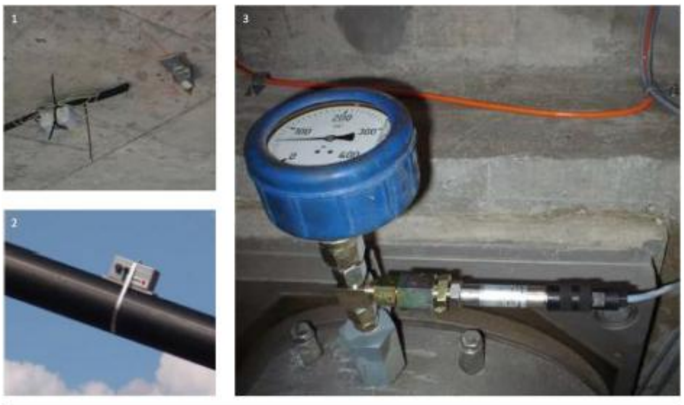

Figure 12. Bearing with measurement of pressure through manometer and load cell.

6.8 *Vibration Sensor*

Measure vibration of different component under different condition. Example of use: in pylon, pier etc.

6.9 *Corrosion Monitoring Sensor*

Monitor corrosion under weather effect. Example of use: in pile, steel member of bridge.

6.10 *Force Sensor*

Measure loading condition under different load like wind, traffic, earthquake etc. Example of use: in bearing.

7 CASE STUDIES

7.1 *Rhine Waterfalls (Switzerland)*

The rock wall of particular interest is about 20m high and was stabilized with 11 additional rock anchors. The installation conditions were challenging due to high exposure, noise and dampness.

Figure 13. Rhine waterfall.

7.1.1 *Problem statement*

The Rhine Falls in Schaffhausen, Switzer-land is visited by hundreds of thousands of tourists every year. It is one of the region's most important tourist attractions and visitors marvel at the beautiful scenery from a terrace at the castle of Laufen.

Rock anchors installed to stabilize the rock wall below the castle showed unexpected force changes, leading to concerns that some sliding surfaces had developed. To ensure the ongoing safety of the terrace, additional rock anchors with measuring devices were installed, with a SHM system monitoring anchor force changes.

This enables the responsible design engineer to draw conclusions about the rock wall's movement behavior, ensuring appropriate action can be taken if required.

7.1.2 *Monitoring approach*

SHM system was connected to the installed rock anchors, its flexibility allowing compatibility with the load cells of the anchors.

After the system calibration had been successfully conducted, the long term monitoring was set up, transmitting all data to a central server. The responsible authorities and design engineers are then able to monitor all anchor forces from their own offices, via a web interface.

The designer set some critical limitations for the anchor forces, which are implemented in the alarm notification feature of the SHM system. Should any alarm value be exceeded, immediate notification will be sent by email and SMS to the designer and owner.

7.1.3 *Outcome and benefit*

It could be concluded that the rock wall has been well stabilized by the additional rock anchors. The forces are now very stable and rock movements are negligible.

And although movements may develop in the future, the SHM system's alarm feature gives the local authority the confidence it needs to safely manage one of Switzerland's most frequented and spectacular public terraces.

7.2 *Incheon Grand Bridge (South Korea)*

Twelve point three km long and with a main cable stayed span of 800 m, the new Incheon Bridge is one of the five longest of its type in the world. Its 33.4 m wide steel/concrete composite deck carries six lanes of traffic 74 m above the main shipping route in and out of Incheon port and links the new Incheon International Airport on Yongjing Island to the international business district of New Songdo City and the metropolitan districts of South Korea's capital, Seoul. The cable stayed section of the crossing is 1480 m long, made up of five spans measuring 80 m, 260 m, 800 m, 260 m and 80 m respectively.

7.2.1 *Problem statement*

The design of this exceptional bridge required deck expansion joints with extraordinary movement capacity (1920 mm). The bridge engineers required verification of:

- The forecasted movement behavior of the bridge.
- The overall functionality of the modular expansion joints on a continuous basis.

7.2.2 *Monitoring approach*
In order to measure the movement of the cable stayed bridge section and the performance of the 24-gap modular expansion joints, a BHM system measures the longitudinal and transverse movements of the deck at the joint.

The system measures the longitudinal movements of the first, second and last lamella beams of the joint, and the entire gap width. It also measures deck rotations and air and structural temperatures.

7.2.3 *Outcome and benefit*
Measurements to date allowed the following conclusions to be drawn:

– The foreseen design movement and rotation behavior of the bridge deck was confirmed
– The exceptional expansion joint is performing very well, with no impacts and with satisfactory opening and closing of all gaps.

Figure 14. Incheon Bridge.

Figure 15. Cable stayed structure of the Incheon Bridge.

7.3 *River Suir Bridge (Ireland)*

The River Suir Bridge is part of the N25 by-pass of the city of Waterford. The cable stayed structure has an overall length of 465 m, with individual spans of 40 m, 70 m, 90 m, 230 m and 35 m, and a width of 30.6 m. Its concrete pylon has a height of 95.6 m above the deck, and the bridge was completed in September 2009.

7.3.1 *Problem statement*
The design of this cable stayed bridge was determined to be critically dependent on the dynamic behavior of its cables. The costly installation of stay cable dampers was to be assessed in two steps:

– Assessment of the characteristics of each stay cable by temporary measurements to determine its natural frequency, damping and tension
– Assessment of the ongoing structural health of the bridge to confirm that there is no need for permanent damping of the stay cables, and thus saving the expense of costly damping systems

7.3.2 *Monitoring approach*
Before opening to traffic, measurements on all 76 stay cables using a BHM system were performed, providing data on actual cable forces and cable damping. Afterwards, a BHM system was installed. The system includes 62 measurement channels in total. The data is automatically analyzed on site with an overview of the current situation and graphical representation of the overall performance to date presented in a web interface.

7.3.3 *Outcome and benefit*
Thanks to the data provided by the monitoring system, it could be concluded that it was not necessary to install dampers on all cables, resulting in great financial savings for the client. However, some selected cables may be fitted with well specified dampers at a later date.

7.4 *Angus L. Macdonald Bridge and A. Murray MacKay Bridge (Canada)*

Two suspension bridges connect the city of Halifax in Nova Scotia, Canada across the sea inlet that divides it in two. Having been opened to traffic in 1955 and 1970 respectively, both bridges have already provided several decades of service. The A. Murray MacKay Bridge was renovated in recent years, and similar renovation works are currently being planned for the Angus L. Macdonald Bridge. It will receive an entire new deck, and computer modeling of the deck, verified by measured data, will play a key role in the design process**.**

Figure 15. Murray MacKay Bridge.

7.4.1 *Problem statement*

It was determined that a structural health monitoring (SHM) system should be used to measure and record the movements and rotations of the deck of the Macdonald Bridge at its expansion joints, providing the data needed by the computer modeling. It was also decided to monitor the movements of the previously renovated deck of the MacKay Bridge, so that the changes to the deck support system could be accounted for in the planning of the proposed works.

7.4.2 *Monitoring approach*

Both structures are equipped with BHM systems, with sensors at each tower recording rotations and displacements (both longitudinal and transverse) of the decks of the bridges, as well as data relating to temperature and wind strength and direction. Since the two suspension bridges are similar and located close to each other, comparing their behavior can provide valuable insights.

7.4.3 *Outcome and benefit*

The gathered data was used by the design engineers to verify their computer models and design critical components. It also provided a very interesting insight into the movements of the deck of the MacKay Bridge, showing that it experiences accumulated movements of up to 35 kilometers per year at its expansion joints. Such accumulated movements are many times higher than the movements measured at the deck of the neighboring Macdonald Bridge, which are just 700 m per year at its joints, and thus likely to accelerate wear and deterioration of the bridge's expansion joints and bearings. The understanding of deck movements provided by the SHM system will thus play a crucial role in supporting the planning of renovation works and the correct choice of sliding materials for the bearings and expansion joints.

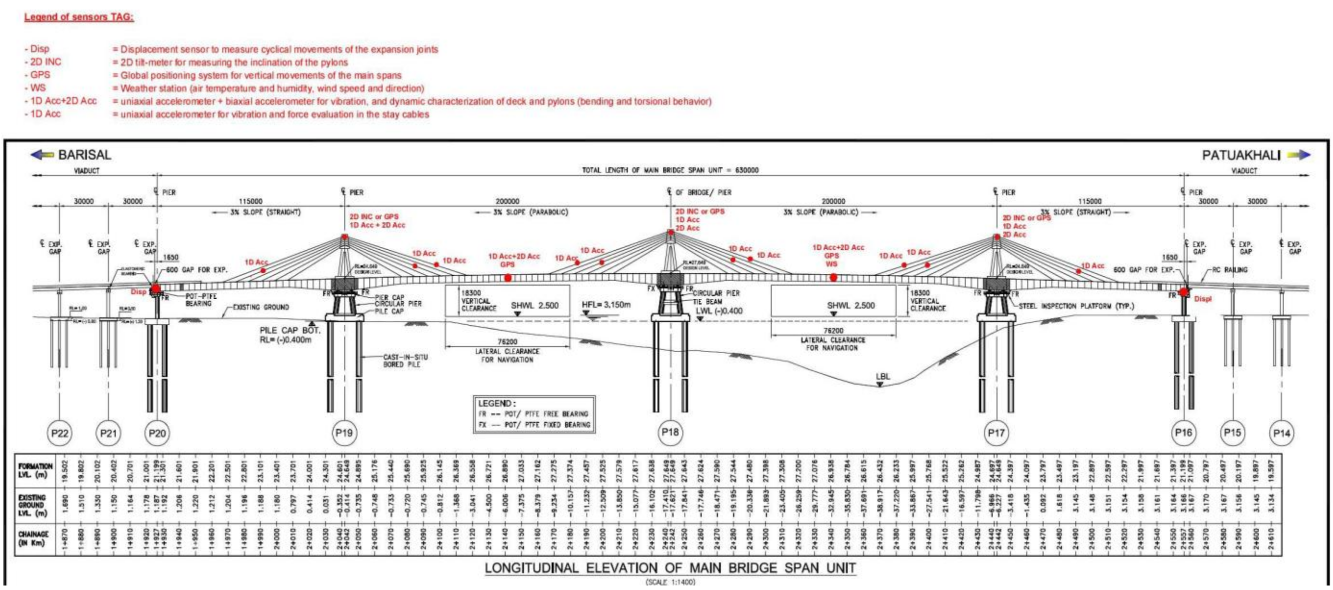

Figure 16. Sensor location.

8 PROPOSED SOLUTION FOR PAIRA BRIDGE

Mageba Bridge Products Private Limited proposed some BHMS solution for Paira Bridge. Their proposed solutions are as follows:

Table 1. Proposed BHMS solutions for Paira Bridge.

Sl. No.	Sensor	Location	Scope	Quantity
1	Displacement sensor	Expansion joint	Measure the daily cycles of longitudinal movements at the expansion joint due to the temperature effects on the deck. To monitor these movements will allow to ensure a proper functioning of the expansion joints.	2
2	Biaxial tilt meter	Top of the pylons	Measure the verticality of inclinations of the pylons. With structural considerations, the movements can be then estimated.	3
3	Weather station	Deck level	Measure the environmental parameters which affect the behavior of the structure (wind speed and direction for vibration of deck and cables, air temperature for longitudinal movements of joints).	1
4	Structural accelerometer	Top of the pylons	One uniaxial accelerometer + one biaxial accelerometer to measure the amplitude of structural vibrations under wind action and dynamic traffic loads. Detection of natural frequencies of bending and torsional behavior for dynamic characterization of the structure.	3
5	Structural accelerometer	Mid span at the deck	One uniaxial accelerometer + one biaxial accelerometer to measure the amplitude of structural vibrations under wind action and dynamic traffic loads. Detection of natural frequencies of bending and torsional behavior for dynamic characterization of the structure.	2
6	Cable accelerometer	Stay cable	One uniaxial accelerometer to measure the amplitude of vibrations under wind action and dynamic traffic loads. Detection of natural frequency and force evaluation.	10

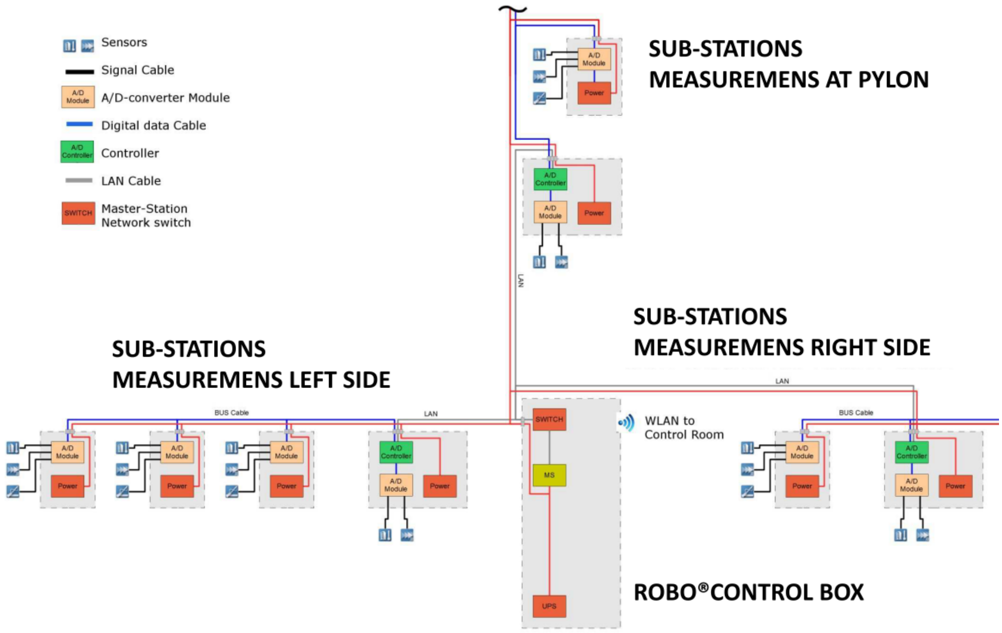

Figure 17. Data acquisition system.

9 CONCLUSIONS

Life Span of Structures need to be increased to ensure sustainable development. With proper health monitoring life of structure can be increased. BHMS give us opportunity to know about any structural damage in real time. So, it is possible to repair quickly and protect structure from greater damage. Proper use of BHMS will increase bridge sustainability.

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