Software Development for Acquisition and Data Management in Optical Sensor Networks


Abstract—Due to their unique characteristics, optical sensor networks have found application in many fields, such as in Civil and Geotechnical Engineering, Aerospace, Energy and Oil & Gas Industries. Monitoring solutions based on this technology have proven particularly cost effective and can be applied to large scale structures where hundreds of sensors must be deployed for long term measurement of different mechanical and physical parameters. Sensors based on Fiber Bragg gratings (FBG) are the most common solution used in Structural Health Monitoring (SHM) and the measurements are performed by special instruments known as optical interrogators. Acquisition rates increasingly higher have been possible using the latest optical interrogators, which gives rise to a large volume of data whose manipulation, storage, management and visualization can demand special software applications. This work presents two real-time software applications developed for these purposes: Interrogator Abstraction (InterAB) and Web-based System (WbS). The innovations in this work include the integration, synchronization, independence, security, processing and real-time visualization, data persistence and flexibility provided by joint work of the applications developed. The results showed the use of these softwares in the laboratory and real environments in accordance with the features proposed.

Index Terms—Software Development, Optical Sensor Networks, Data Acquisition, Data management.

I. INTRODUCTION

Currently there has been a significant increase in the use of software systems in sensor networks [1], [2]. These systems are made to gather data from sensors in order to build the information that defines the real state of the monitoring structure in function of the time. The extraction of valuable information from monitored structures has become a very important and challenging task, mainly due to demand for several techniques to compress and condense data as well as to diagnose the state of what is being monitored [3].

In a wireless sensor network with many sensor nodes measuring different quantities, as well as an optical sensor network using multiplexing, the potential to generate a large volume of data that can become computationally intractable is quite plausible. In [4] was proposed a wireless network sensor information and identification system (WiNS Id) database which archives the data reported by distributed sensors, as well as the implemented support for queries and data presentation. The system features include real-time support for data presentation and visual presentation of sensor nodes reporting in a geographical and temporal context. Additionally, WiNS Id provides support for pattern identification and data mining in sensor systems.

A datawarehouse for management of data from wireless sensors to monitor the habitat of bees was shown in [5]. This work proposes a model to extract, transform and normalize data from sensor networks and load them into a datawarehouse. Thus, this data can be easily analyzed by experts to assist in the process of decision making. However, this work did not present techniques for compressing data generated by sensors, which can be large in volume and impair the process of information retrieval. The assumption that the databases to be integrated are already consolidated was considered, but in practice the treatment of large volumes of data ends up being the most costly part of the system.

The SHM process on huge structures, such as dams and bridges, can demand hundreds of sensors. Smart structures also can be a demanding application in terms of data rate or samples per second. Optical sensors are being deployed in these applications because they are inert, durable, naturally embedded in a reliable optical network and invulnerable to electromagnetic interference [6]. Differently from current wireless sensors based on digital systems, these sensors are analogic. They are based on the principle that the measured information (e.g., temperature, strain, acceleration) is wavelength-encoded in the Bragg reflection of the grating [7], [8]. Measurand changes are coded on wavelength shift of a given Bragg sensor, which are processed by optical interrogator. Interrogators in fiber gratings sensor systems are the measurand-reading units that extract measurand information from the optical signals coming from the sensor heads. The interrogators usually measure the Bragg wavelength shifts and convert the results to measurand data [9], [10]. This data can be stored in a file or made available to client software that establishes communications with the interrogators in accordance with standard protocols.

Although there are already consolidated commercial interrogators, the data acquisition systems offered with them usually are based on private data formats or databases incompatible with other systems or brands. Until current date, there are not a commercial or open datawarehouse for SHM capable of gather data from different technologies and optical interrogators. This paper proposes such a monitoring system, composed of two softwares, capable to collect, process, persist, retrieve, manage, and present data from optical sensor networks. The InterAB System and WbS will be described based on their features and their individual contributions to the overall integrated monitoring system. The paper is organized as follows: the SHM background is presented in Section II; the InterAB and WbS features are detailed in Sections III.
and IV, respectively; the Section V demonstrates how the integration is achieved between softwares; the Section VI presents and discusses test results; final remarks and future work are presented in Section VII.

II. THE CORE ACTIVITIES OF THE SHM PROCESS.

The SHM process consists of permanent, continuous, periodic or periodically continuous recording of parameters that reflect the performance of the structure [11]. Depending on the type of the structure, its condition and particular requirements related to a monitoring project, SHM can be performed in the short term (typically up to few days), mid term (few days to few weeks), long term (few months to few years) or during the whole lifespan of the structure.

The representative parameters selected to be monitored depend on several factors, such as the type and the purpose of a structure, expected loads, construction material, environmental conditions and expected degradation phenomena [12]. In general, they can be mechanical, physical or chemical. The most frequently monitored parameters are presented in Table I. Our work focuses mainly on monitoring mechanical parameters (strain and acceleration) and partially on physical parameters (temperature) using optical sensors.

<table>
<thead>
<tr>
<th>Class</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>Strain, acceleration, deformation, displacement</td>
</tr>
<tr>
<td>Physical</td>
<td>Temperature, humidity, pore pressure</td>
</tr>
<tr>
<td>Chemical</td>
<td>Chloride penetration, pH, steel oxidation</td>
</tr>
</tbody>
</table>

The core activities of the structural monitoring process are: selection of monitoring strategy, installation of monitoring system, maintenance of monitoring system, data management and closing activities in the case of interruption of monitoring [12]. In particular, data management can be split in to sub-activities, such as: execution of measurements (reading of sensors), storage of data (local or remote), providing for access to data, visualization, export of data, interpretation, data analysis and the use of data (warnings and alarms).

The software applications proposed in this work will be responsible for these sub-activities of data management in the structural monitoring process.

III. ACQUISITION, PROCESSING AND PERSISTENCE: INTERAB SYSTEM

The InterAB System is a Java application responsible for communication, acquisition, compression and data persistence (storage). The InterAB implements the optical interrogator’s communication protocol. The InterAB operation is shown in Figure 1. The application interacts via TCP/IP socket and threads with optical interrogators, which collects the samples generated by the sensor network, in order to receive the real-time monitoring data. The samples are wavelengths shifts that indicate changes in the measured parameter by the sensor. The InterAB then processes the data that were transmitted by the interrogator in a format SCPI (Standard Commands for Programmable Instruments) and the system communicates with the database through JDBC connection (Java Database Connectivity) to persist the compressed samples for each sensor.

Additionally, the data compression techniques implemented in InterAB aim to reduce the amount of records, from the structural monitoring with sensor networks, which are inserted into the database [14]. The following techniques were implemented: variation in the wavelength and activity.

The compression by variation in the wavelength is suitable for parameters that varying slowly, such as temperature. In terms of structural monitoring, the temperature usually does not show significant changes in a short amount of time, except in cases of damage in structure. Therefore, in most cases it is not necessary to store a large volume of measurement data that does not represent interesting variations in temperature. The process is performed by comparing the last sample $s_i$ collected with the last sample $s_j$ that was actually inserted into the database. If $|s_i - s_j| > \Delta T$, then $s_i$ is inserted into the database. The parameter $\Delta T$ defines the accuracy and intensity of the compression system. When $\Delta T$ is large, fewer samples are inserted into the database. For temperature optical sensors based on FBG, the accuracy in Celsius degrees is 0.1°C, this value is a minimal value for $\Delta T$.

The compression technique based on activity is suggested for data from acceleration and strain optical sensors. An essential element of this technique is the identification of a relevant event or activity. This work proposes the use of the absolute difference between the acceleration (or strain) recorded by the last sample and the average of last $n$ samples:

$$\Delta s_i = \left| s_i - \frac{1}{n} \sum_{k=i-n}^{i-1} |s_k| \right|, \quad (1)$$

where $\Delta s_i$ is the absolute difference and $s_i$ is the last sample collected by interrogator. The subscript indicates the sample collection order.

![Fig. 1. InterAB System performing data acquisition from multiple optical interrogators.](image)

Since the data are stored in the database any desktop or Web application can retrieve this information for various purposes, such as visualization, decision making and diagnosis.
IV. SECURITY, REAL-TIME VISUALIZATION AND ANALYSIS: WEB-BASED SYSTEM

The Wbs is a Java Web application responsible for retrieve, export, visualization and generation of alerts and alarms from monitoring data stored into the database by InterAB or any other application. The WbS operation is shown in Figure 2. First, a user of application performs a request for content (for example, data export, visualization, interpretation and analysis, or warnings and alarms). Then, the WBS application receives and processes the request according to what was requested by the user. Subsequently, based on the user request, the Wbs retrieves the corresponding data in a relational database via JDBC communication. Finally, the retrieved data is presented to the user in the form of charts, tables, graphs, files, forms, alerts and alarms.

![Fig. 2. The operation of the WbS.](image)

For the monitoring of a target structure was developed a Web-based application totally independent of the acquisition, processing and persistence performed by InterAB, therefore only the information present in the database is required. The WbS development on the Java programming language together with the JSF (JavaServer Faces) [15] front-end framework inheriting the flexibility, integration, mobility and security afforded by these platforms, once the application becomes visible for any computer in the Internet.

The WbS is composed of a security mechanism implemented by Spring Security Web framework that performs authentication checks and login, thus the most critical system areas are restricted to people with certain privilege types. Once the communication is established, the user can edit the optical sensor network settings and proceeds tasks such as data analysis, export, visualization and the use of data (warnings and alarms). The PrimeFaces [16] Web framework coupled to Web application aims to implement statistical graphs, tables, forms and computational analysis.

Through virtual version of the optical sensor network persisted in the database by InterAB, the Wbs creates a Web version of the sensor network physical topology, which is an interactive and automatically updatable graphs that describes the current optical sensor network architecture. Each sensor type has a specific conversion formula, which is called calibration equation, that converts the peak wavelength of the FBG sensor to its corresponding measurement. These conversions are performed using first or second order equations that are provided by datasheets.

The WbS and all features mentioned above are generally exemplified in the following features diagram shown in the Figure 3. The diagram illustrates the four layers in the WbS: visualization layer for user interaction, processing layer and business rule layer to perform the treatment and data management, and communication layer (Hibernate) for manipulation and data persistence in the database.

![Fig. 3. WbS features diagram.](image)

V. FLEXIBILITY, INDEPENDENCE AND INTEGRATION BETWEEN INTERAB AND WEB-BASED SYSTEM

The interAB and WbS are applications that can work independently or jointly. The interaction between softwares are possible by sharing the same database, as shown in Figure 4. The InterAB System performs the acquisition, processing and data persistence, at the same time populating a update table that records data inserts in the database. These updates are often checked by the WbS in order to update the data being made real-time available to the user. In the applications context, Hibernate [13] is characterized as a communication interface between the database and the systems, since all persistence operations and data reading is actually performed by the queries generated by this framework that maps objects automatically for the relational database.

InterAB and WbS can ensure high flexibility in the optical sensor networks monitoring. This flexibility is made feasible due to the fact that these applications easily adapt to the most types of interrogators and sensors. For interrogators is necessary to know its communication protocol and sampling rate. And for optical sensors must be known its reference wavelength and calibration equation.

VI. RESULTS

Aiming to present the main features of the InterAB System and WbS, two tests were proposed in different environments. The first environment is a laboratory test, where temperature is measured under controlled conditions.
The second environment is a real test performed on metal walkway with approximately 40 m long. The measurements collected were temperature, strain and acceleration from 8 sensors installed along the metal walkway. Each environment used different interrogator equipments and set of sensors, as shown in Table II.

### TABLE II
**COMPONENTS FOR EACH ENVIRONMENT**

<table>
<thead>
<tr>
<th>Environment</th>
<th>Interrogator Type</th>
<th>Sensor Type</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory</td>
<td>Rack-Mountable BraggMETER</td>
<td>Temperature</td>
<td>1 S/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strain</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acceleration</td>
<td>1</td>
</tr>
<tr>
<td>Real</td>
<td>Industrial BraggMETER</td>
<td>Temperature</td>
<td>100 S/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strain</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acceleration</td>
<td>2</td>
</tr>
</tbody>
</table>

**A. Test in a laboratory**

The scheme for the test is presented in Figure 5. This scheme presents a temperature sensor in the three channels of the optical interrogator and a strain sensor in the other channel. The test carried out the temperature monitoring by three sensors (WTS) and the strain monitoring by one sensor (WSS). The sensor network topology recognized by InterAB and visualized by WbS is shown in Figure 6.

**B. Test in a real environment**

The real testing environment is characterized by a metal walkway with approximately 40 m long. The walkway and examples of FBG sensors are shown in Figure 8. An optical cable of approximately 500 m connects the sensor network installed in the walkway with the interrogator located in the laboratory. The structural monitoring is carried out by an optical sensor network composed of three temperature sensors, three strain sensors and two acceleration sensors.

This test presents the features export and preview data provided by WBS. The screen regarding this functionality is shown in Figure 9. The user selects the sensor types and chooses the intervals to select the data. Using the export button the data are saved in an export file format recognized by Octave, Matlab, R and Weka. The update button shows a
optical interrogators and environments, ensuring atomicity, consistency, isolation and durability of persisted data by InterAB and displayed by WbS. For the next steps we intend to integrate the system features such as fault detection, structural damage detection, new filtering techniques and develop a Web service that can perform a more robust data management.

REFERENCES


VII. FINAL REMARKS AND FUTURE WORKS

The paper presented a monitoring system for optical sensor networks composed of InterAB and WbS which together perform the acquisition, processing, persistence, management and visualization of data obtained from the interrogation systems. The results obtained during tests in a laboratory and in a real environment demonstrate the efficiency, robustness and flexibility of the system for different types of sensors,