Software Development for Acquisition and Data Management in Optical Sensor Networks

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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 and Gas Industries. Monitoring solutions based on this technology have proven particularly cost effective when applied to large scale structures where hundreds of sensors must be deployed for long term measurement of different physical parameters. Fiber Bragg gratings (FBG) are the most reliable solution in some harsh environment applications where the sensors are submitted to extreme electromagnetic interference. 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 be performed by 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]. The efficient integration of this information from these systems has become a very important task. This led to the growing challenge for sensor technology industry to develop new concepts, techniques and softwares [3]. One of the motivators of this fact is due to the increasing use of systems called standalone, which are systems that work independent of others. If these systems share the same database there not will be issue about this approach, otherwise, data integration will be an essential requirement to change the existing data [4].

In a wireless sensor network with many sensor nodes measuring different quantities, as well as a optical sensor network using multiplexing, the potential to generate a large volume of data that can become computationally intractable is quite plausible. The optical sensing is based on the principle that the measured information (e.g., temperature, strain, acceleration) is wavelength-encoded in the Bragg reflection of the grating [5], [6]. Measurand changes are coded on wavelength shift of a given Bragg sensor, which are processed by optical interrogator. Interrogators in fiber grating 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 [7], [8]. 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.

A WEB controlled interrogation system to determine the peak wavelength of the reflection spectra of Bragg gratings is modeled in [9]. This system is based on a scanning Fabry Perot interferometer, whose electronic control unit has been modified to allow automated operation under external micro-controlled supervision. A micro-controller with embedded Web server capabilities is used to permit the access through the Internet.

In [10] is 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 is shown in [11]. This paper proposes a model to extract, transform and normalize data from sensor networks and load them into a data warehouse. Thus, this data can be easily analyzed by experts to assist in the process of decision making. However, this paper shows no filtering technique of data generated by sensors, which can be large in volume and impair the process of obtaining information. This is on the assumption that the databases to be integrated are already consolidated, but in practice the treatment of large volumes of data ends up being the most costly part of the system.

A dynamic model is proposed in [12] that considers the advantages of different storage models such as the local, external and data-centric model. The data transmission management is critical in wireless sensors networks, due to the high impact on overall energy consumption.

From the literature review there is not software applications for monitoring in optical sensor networks. This paper proposes 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 section II demonstrates how the integration is achieved between softwares; the InterAB and WbS features are detailed in Sections III and IV, respectively; the Section V presents and discusses test results; final remarks and future work are presented in Section VI.
II. 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 1. 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.

III. ACQUISITION, PROCESSING AND PERSISTENCE: INTERAB SYSTEM

The InterAB System is an Java application responsible for communication, acquisition, filtering and data persistence. The InterAB System implements the optical interrogator’s communication protocol. The InterAB operation is shown in Figure 2. 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 quantity by the sensor. The InterAB then processes the data that is 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 filtered samples from each sensor. Additionally, InterAB can apply, before database persistence step, filtering techniques depending on the quantity measured by the sensor: filtering technique based on the variations in wavelength that proposed for data from FBG temperature sensors or filtering technique based on activity that suggested for data from FBG acceleration and strain sensors. A review about the filtering techniques is presented in [14].

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, PROCESSING AND REAL-TIME VISUALIZATION: WEB-BASED SYSTEM

For the monitoring of a target structure was developed a Web-based application totally independent of the acquisition, processing and persistence system, so that only the information present in the database is required. The WbS development on the Java programming language in conjunction with the JSF (JavaServer Faces) [15] front-end framework inheriting the flexibility, integration, mobility and security afforded by such platforms, once the application becomes visible from any equipment that has Internet connection.

The WbS is composed of a security mechanism implemented by Spring Security Web framework that performs authentication checks and login so that 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 and visualization, and apply techniques for faults detection on the system. The PrimeFaces [16] Web framework coupled to Web application implementing statistical graphs, tables, forms and computational analysis tools.

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.

![WbS features diagram](image)

V. 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 I.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>COMPONENTS FOR EACH ENVIRONMENT</th>
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<tbody>
<tr>
<td><strong>Laboratory test</strong></td>
<td><strong>Real test</strong></td>
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<tr>
<td>Interrogator</td>
<td>Interrogator</td>
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<tr>
<td>Rack-Mountable BraggMETER</td>
<td>Industrial BraggMETER</td>
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<tr>
<td>Type</td>
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<tr>
<td>Strain</td>
<td>1</td>
</tr>
<tr>
<td>Acceleration</td>
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</table>

A. Test in a laboratory

The scheme for the test is presented in Figure 4. 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 5.

![Scheme for test in a laboratory](image)

Fig. 5. Sensor network topology recognized by InterAB.

B. Test in a real environment

The collected, processed and data persisted by InterAB could be visualized by WbS in Figure 6. In this test the InterAB System performs filtering on data generated by optical sensors. A variation in the peak wavelengths of the temperature sensors occurs due to a variation in the temperature. The filtering was performed only on data that were consistent with certain wavelength variation set up previously. The graphics show the real-time variation of the data collected, being updated automatically with the last new one hundred samples saved in database.

![Visualization provided by WbS](image)

Fig. 6. Visualization provided by WbS.
examples of FBG sensors are shown in Figure 7. An optical cable of approximatelly 500 m connects the sensor network installed in the walkway with the interrogator located in the laboratory. The structural monitoring is carried out by a optical sensor network composed of three temperature sensors, three strain sensors and two acceleration sensors.

![Acceleration (g)](image)

Fig. 7. Scheme for test in a real environment.

This test presents the features export and preview data provided by WBS. The screen regarding this functionality is shown in Figure 8. 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 preview of data that are available for download, as can be seen in Figure 9.

![Select Interval](image)

Fig. 8. Export and data preview.

VI. 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, 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.

![Acceleration (g)](image)

Fig. 9. Preview of accelerometer sensor data.

REFERENCES


