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CONCEPT AND DESIGN OF A WIRELESS REMOTE MONITORING SYSTEM FOR THE AQUEDUCT OF QUERETARO

Roberto Alvarado Cárdenas
ITESM Campus Querétaro1

Francisco Carrión Viramontes
Instituto Mexicano del Transporte1

Alejandro Aragón Zavala, Eduardo Rosado Colmenares, César Cárdenas Pérez,
ITESM Campus Querétaro2

ABSTRACT:

The purpose of this research is to develop monitoring tools that provide information on the current state of the Aqueduct of Queretaro's structure.

Through the placement of wireless accelerometers, MEMS sensors, at diverse points of the structure, vibration readings are concentrated at a data station using a local communication interface and transmitting them with an external communication interface to the remote monitoring center using File Transfer Protocol (FTP).While the total length of the aqueduct is close to 1300 meters, the system was designed for the monitoring of a critical traffic intersection, which is located in a 110 meters segment (7 arches), thus, the wireless system specification was to cover a 200 meters range with, at least, 16 sensors.

Since the aqueduct is in the urban area of the city of Queretaro, the system required additional high frequency filters to avoid external noise from high voltage energy transmission lines and telecommunication devices. Connection to the monitoring center was done through a 3G Internet link, and data post analysis considered historic structural analysis with a set of alarms to prevent anomalous or extreme vibration levels, particularly during the construction of a new intersection to increase traffic capacity in surrounding areas. The overall system concept proved to be effective for a temporary remote monitoring of the segment in the critical intersection.

Keywords: Civionics, Wireless remote monitoring, Structural integrity, Vibration analysis, wireless instrumentation.

1 INTRODUCTION

The Aqueduct of Queretaro is an icon of this city that for centuries has been firmly standing as a symbol of the wit, capacity and technical ability of Queretaro's people.

Figure 1 Panoramic Photograph of the Aqueduct of Queretaro

Even though nowadays the Aqueduct is not providing water to the city as it was originally built for, it still maintains the ideals and commitments that engineers, architects, professionals and members of Queretaro's society have to preserve the growth of the city and its infrastructure under a sustainable perspective.

As the city has grown through time, this monument has claimed its space and has inserted itself as one of the principal axis basic in the drawing of the city and its system of roads. The dramatic growth of traffic, especially on Bernardo Quintana Boulevard, boulevard that goes through the Aqueduct, is a challenge to the integrity of this majestic construction.

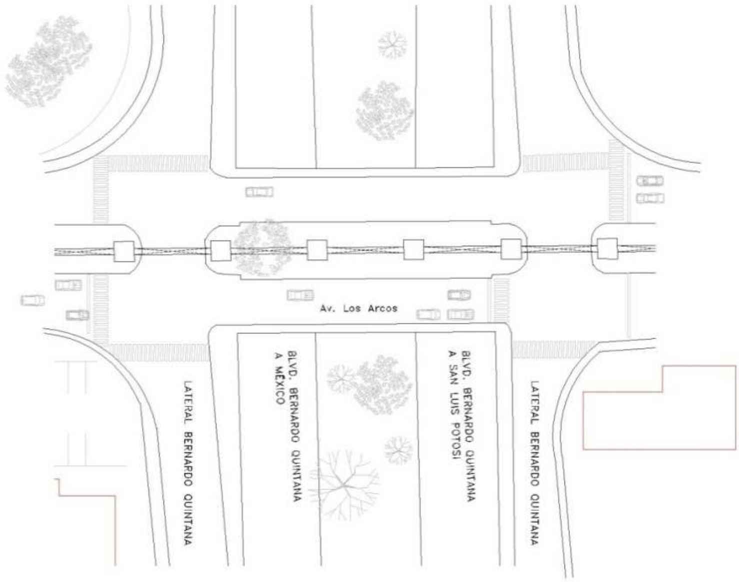

Figure 2 Sketch of the intersection between Bernardo Quintana Boulevard and Los Arcos Avenue

In the 1970's, two tunnels were built to work as underpasses so Bernardo Quintana Boulevard, one of the principal roads of the city, could run under Los Arcos Avenue.

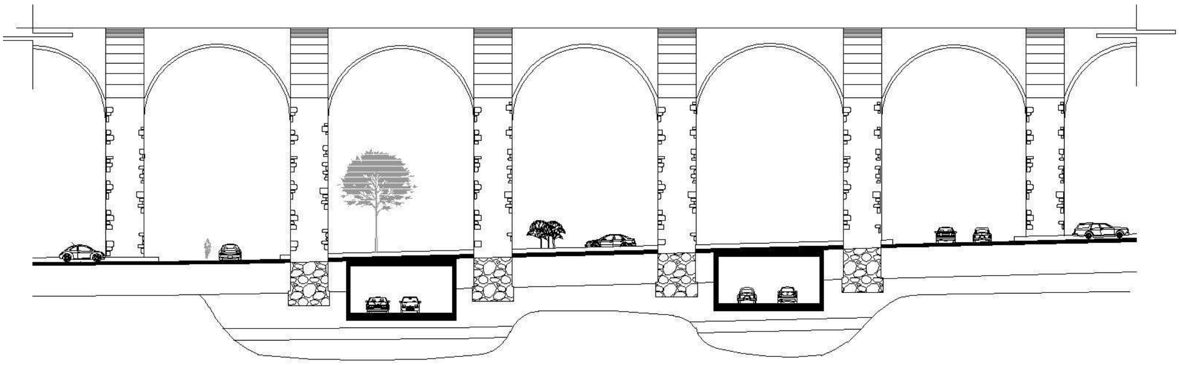

Figure 3 Transversal sketch of the intersection between Bernardo Quintana Boulevard and Los Arcos Avenue

Due to the great amount of traffic at this intersection, the plan on the short-run is to modify the crossroads and the tunnels that run under Los Arcos Avenue to increase the number of lanes.

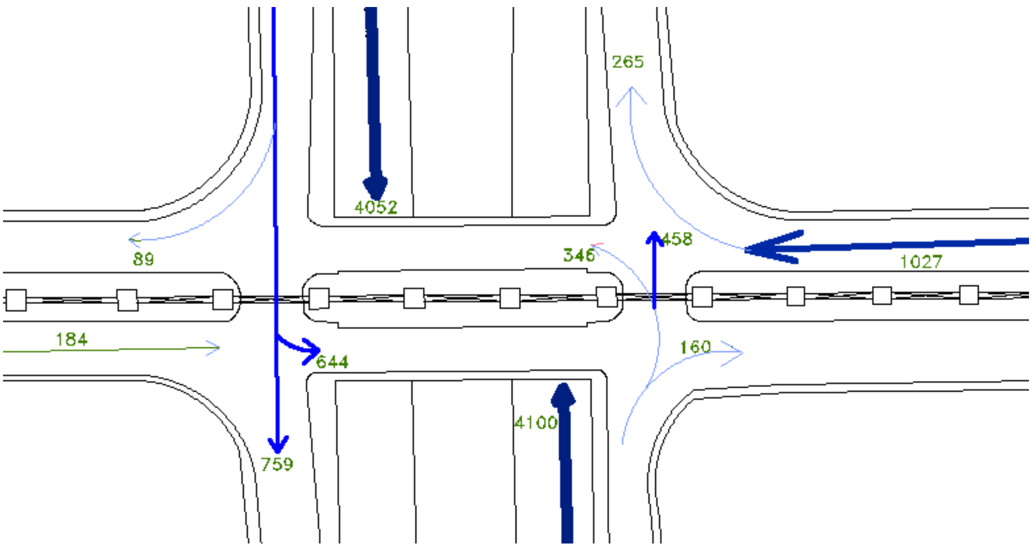

Figure 4 Traffic density at the intersection of Bernardo Quintana Blvd. and Los Arcos Ave.
(Monday, November 8, 2010 7:00-8:00 am)

In the view of this situation, specialists in different disciplines have contributed with several researches and information of the immediate environment, of the attributes of the monument and of the effect of the conditions that the structure of the Aqueduct faces at the moment. These contributions turn out to be quite appropriate and therefore this research intends to contribute as well from the view of Civionics a historical view of the monument's dynamic behavior through permanent remote monitoring of the effects of the environment on the structure of the Aqueduct.

This project is, metaphorically, an "electrocardiogram of Queretaro's giant", the one we want to preserve so it can still give testimony of the commitment and the respect for the identity of Queretaro's people.

2 CIVIONICS

Civionics is the field of Study that incorporates Civil Engineering with Electronic Engineering. One of the mayor applications of Civionics is the Structural Health Monitoring (SHM). SHM provides information necessary to optimize design techniques to understand the performance of structures, their behavior and their condition in real time.

Based on the implementation of a monitoring remote system, a detailed tracking of the behavior of structures and monuments as important as the Aqueduct of Queretaro is available in real time. In this way damage can be easily evaluated and detected, especially when the structure is subject of extreme conditions or extraordinary events occur.

3 WIRELESS REMOTE MONITORING SYSTEM ON THE AQUEDUCT OF QUERETARO

The development stages of theWireless Remote Monitoring System on the Aqueduct of Queretaro are the following:

1. Selection of the monitoring points
2. Instrumentations and data acquisition through wireless accelerometers (ZigBeeTM technology)
3. Validation of communications systems
4. Gathering of data on the data acquisition system
5. Data transmission
6. Recollection and gathering of measurements
7. Development of interfaces for query and graphic display

4 TECHNOLOGY FOR THE INSTRUMENTATION AND DATA ACQUISITION

ZigBeeTM is the name of a specification that consists on a series of high level protocols for low power, high performance battery life and low data transmission rate wireless communications.

Figure5ZigBeeTM Transmitters

The ZigBeeTM standard is based on the IEEE 802.15.4 specifications for wireless networks in Wireless Personal Area Networks (WPAN). The purpose of the standard is to enable safe communications with a low rate of data transmission and the extension of the battery life for applications of distributed sensors networks.

It is expected that domotics is the area that will most demand this type of communications; never the less, all the applications related to the field of Wireless Sensor Networks (WSN) consider it as the standard *de facto*. The most important advantages mentioned by ZigBeeTM Alliance, the group that developed the standard, are: low power consumption, the possibility to enable grid network topology and its easy integration on small electronic devices.

The grid network topology allows the extension of the WPAN based on ZigBeeTM in long distances without a central control that limits the special reach. The ZigBeeTM standard is similar to the BluetoothTM because they are both based on the IEEE 802.15 standard. The difference lays on the development group: BluetoothTM was developed by workgroup 1 and ZigBeeTM, by workgroup 4. Both have different physical and access layers and their respective workgroups keep updating the standard according to the advances in modern applications.

ZigBeeTM works on ISM frequencies (Industrial, Scientific and Medical frequencies), while BluetoothTM and Wi-FiTM work on most of the short-range communications. The co-existence among several systems is topic of concern for investigation groups. Because of its low power consumption, its long battery life, its reach that ranges between 10 and 100 meters and its low transfer speed rate, ZigBeeTM is the most adequate choice for monitoring through wireless.

5 INFORMATION TRANSFERENCE ARCHITECTURE

For the Remote Monitoring System on the Aqueduct, architecture like the one shown on Figure 6 was used. The data was taken directly from the electronic accelerometers installed on specific points on the structure which voltage output is proportional to the vibrations. This voltage signals are sampled by an acquisition data card connected to a computer.

It is worth to mention that every sensor signal is analogical, and when sampled is converted to digital. This computer has an acquisition data software installed, LabView of National Instruments, which prepares and processes the information to be sent.

From the receptor located at ITESM Campus Querétaro, it is possible to send configuration commands to the Remote System, where the frequency used to sample, among other relevant parameters, is settled. This is why on Figure 6 the communication between transmitter and receptor is shown as bidirectional.

The communication system is formed by a wireless cellphone modem that works with 3G technology. This modem receives the data through a USB port on the computer where LabView is running and connects itself to the network using the FTP protocol, a universally accepted protocol for transmitting data between computers and servers. The advantage of using a cellphone network instead of using a wireless WiFi is that the cellphone network accessibilitycan be guaranteed more easily than the WiFi network. The coverage of the cellphone network is wider because of the features and the power of the transmissions. Also, the data transference through this network is safer as its cryptographic algorithms are stronger than the WiFinetwork's.

Once the transmitter has been connected to the 3G network, it is possible to access Internet as well as to write and download files from the web. Given this possibility, a link is made to a server installed at ITESM Campus Querétaro, called "Siqueiros", where the samples of the vibrations coming from the Aqueduct are sent and then stored in a database. From this server, the necessary data is extracted to generate reports on a website, later detailed in this article.

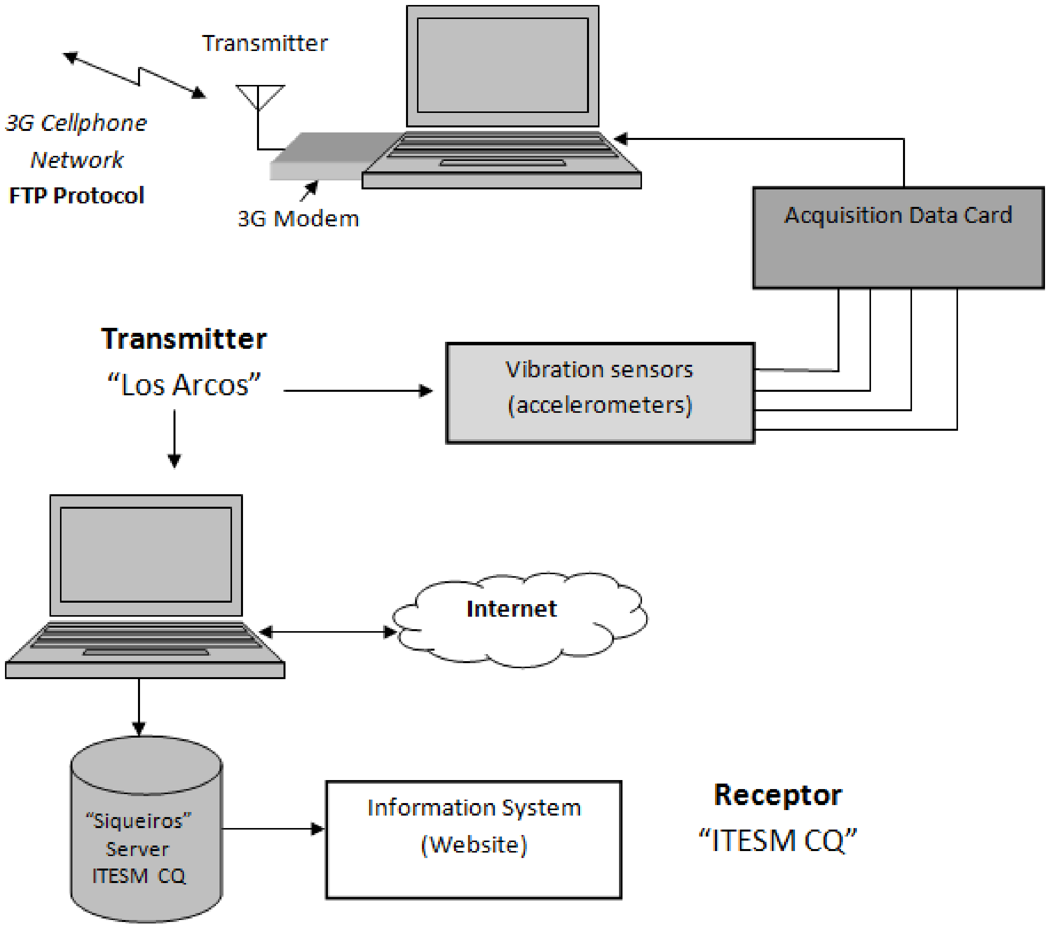

Figure6 Architecture of the Remote Monitoring System through 3G cellphone network

Besides having the possibility to be remotely configured, this Remote Monitoring System has the advantageof having access to real time information of the vibrations that are being registered at the moment, as well as consultation and updating of the repository of this information after the event happened.

6 INFORMATION CONCENTRATION AND CONSUTATION OF MEASUREMENTS

In order to make possible the remote monitoring through the consultation of the historical measurements of the vibrations, the software components shown in the diagram below were built and integrated:

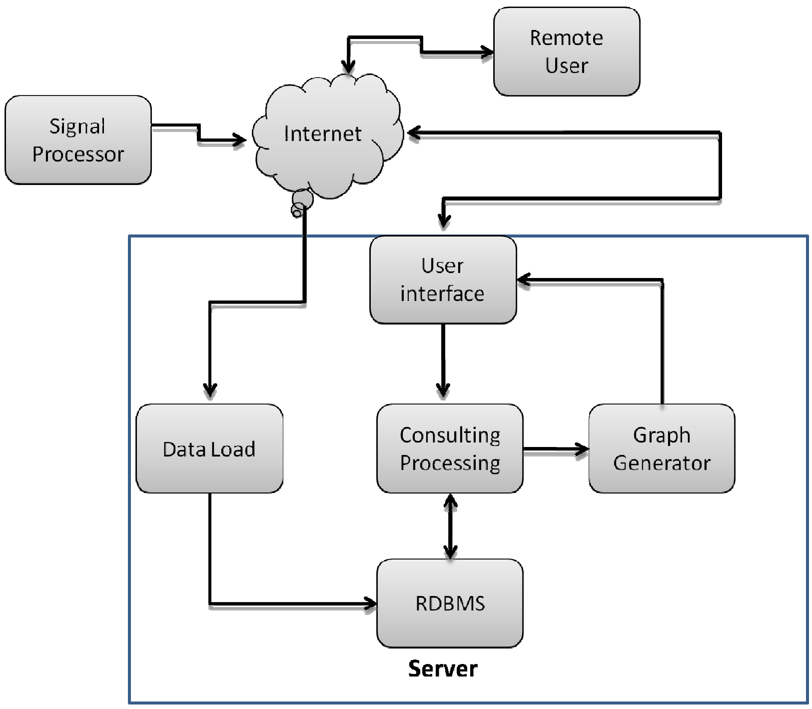

Figure7Recollection and storage of measurements

Once the signal processor has done the sampling tasks and filtered the values received from the vibration sensors, the measurement data is sent to the server through Internet, using FTP and stored as a text file as Comma Separated Values (CSV). This occurs periodically, at intervals determined by the frequency of sampling and fixed in a minimum time to assure that the data load can be processed.

The data load component uses the services of Relational Database Management System (RDBMS) to store themeasurement data on a database for its later consultation. This component also executes itself periodically to synchronize with the signal processor through the identification of the precise moment of each timestamp. In this way, in order to decide whether the content of the CVS file generated by the signal processor should load in a particular time, it is enough to verify if the timestamp of the first measurement is contained in the file and determinewhether it is found on the database or not.

The recollection mechanism, allows the storage of a great amount of measurement data on the database. By using the RDBMS services data from different periods, consultations of both the most recent measures and the historical sampling, either in detail or grouped in specific time intervals with average calculations can be made.

7 GETTING GRAPHS FOR REMOTE MONITORING

In order to make possible the remote monitoring of vibrations, an interface, with the cooperation of the user, was built.It allows the access using a browser through the HTTP Protocol (Hypertext Transfer Protocol), so that in any place in which the user has Internet, he can consult both the recent measurements and the historical data stored in the database.

The interface allows the user to either select the period of measurements he wants to consult or consult recent measurements with a periodically update frequency of the consultation. The user can ask for the detailed measurements by sample frequency registered, or grouped by different ranges of time.

Based on the selection criteria asked by the user, the processing component of consultation builds the request to the RDBMS, extracts the measurements and organizes the results in the XML format (eXtensible Markup Languague) requested by the graph generator. This system graphs the obtained results, showing them on a SWF file (shockwave flash file) and presents it through the interface.

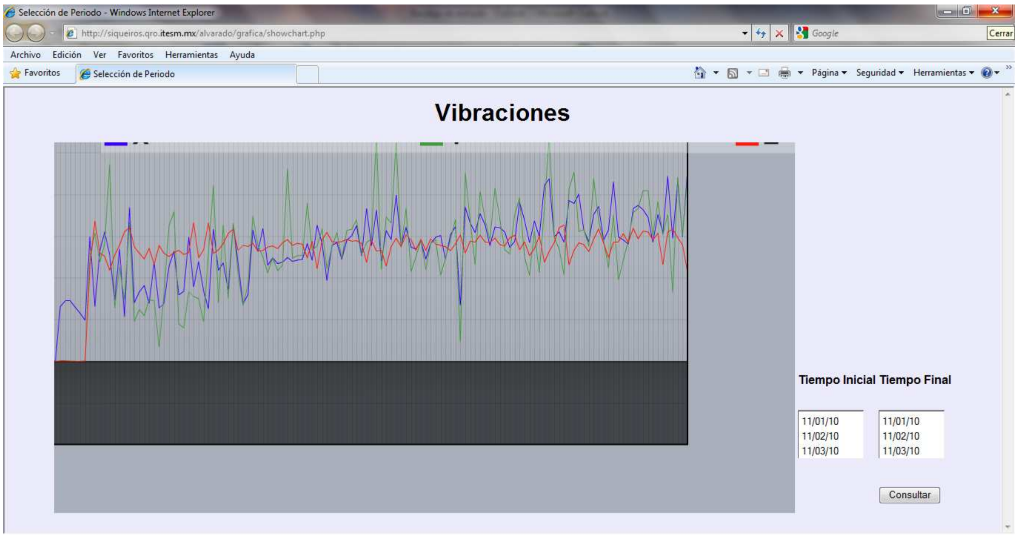

Figura 8 Remote Monitoring System Interface

The user interface and the consultation processing were created using PHP (V. 5.2), open source platform used for the development of Internet applications, on which the SQLSVR library was included for the RDBMS interaction, Microsoft SQL server 2008. The load database component was developed using stored procedures with scheduled jobs within the same RDBMS. To build the graph generator, the PHP/SWF Charts(www.maani.us/charts) library was used; it combines the PHP development with graph templates generated with Adobe Flash, to be embedded to HTML, and receive the data to be plotted and the graphic configuration through XML.

8 CONCLUSIONS AND FUTURE WORK

With the current technology is possible to obtain data of the effects of external elements on the Aqueduct of Queretaro. This is valuable information to keep a record of the current behavior of these elements during the roadworks happening on the surroundings of the monument, and those after those works.

As the next stage of this research, it is scheduled to: implement a module design of integral evaluation of the structure,develop specialized models of EF, develop statistic global models, and integrateevaluation models. The purpose will be to achieve the development and implementation of conservation programs of the Aqueduct of Queretaro.

9 ACKNOWLEDGEMENTS

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