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SHM DATA MANAGEMENT SYSTEM USING MYSQL DATABASE WITH MATLAB AND WEB INTERFACES

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ABSTRACT: This paper represents a SHM data management system (SDMS) built on MySQL database management system (DBMS) for efficient storage, retrieval and sharing of extremely large measurement data sets constantly acquired from SHM systems. The SDMS have a MATLAB interface and a web interface so that SHM researchers can access vast data sets of the SDMS easily and instantly. MySQL is a relational DBMS with open sources, freely usable under the GNU General Public License. Two types of database tables were utilized in the data management system: 1) time history tables and 2) a summary table. Time history tables store raw time history measurements from each measurement system. After data processing or averaging for each 30 minutes record of high-rate sampled data, a compressed or represented value is stored into the summary table in order to provide an overview of the full data set. MATLAB interfaces to the database are developed based on mYm, an open source MySQL Wrapper for MATLAB, to retrieve SHM data into the MATLAB workspace with a few simple commands and to store processed results back into the database. Application examples of the SDMS are presented for Tamar Bridge and Humber Bridge.

1 INSTRUCTION

A data management system is a key element of SHM systems to support data mining or knowledge discovery from vast amount of data covering design, construction, maintenance details and measured response of the structure. Conventional ways of storing information in forms of reports, drawings, and photos on shelves and raw measurement files in a PC possibly make the data mining process slower or even practically not achievable. A SHM data management system comprised of a relational database management system, a web server, and a file server can make all relevant SHM data accessible instantly and easily to all the relevant peoples of SHM researchers, structure operators, and structural designers.

In the field of SHM, use of relational database management systems (RDBMS) has got popular recently mainly for storing sensor measurements and derived quantities as shown in a building SHM proto-type system with a web-server interacting with MATLAB (Mita, Inamura et al. 2006), Connecticut's Bridge (Josh and John 2007), Burj Khalifa (Kwon, Kijewski-Correa et al. 2010), GuangZhou TV Tower (Ni and Zhou 2010), Voigt Drive/I-5 Bridge (Michael, Ahmed et al. 2010), and a wind turbine

(Smarsly, Law et al. 2011). Data-modeling aspect of RDBMS for SHM purposes have been studied (Inaudi, Glišiæ et al. 2002; Tiwari and Brown 2006).

To support knowledge discovery from databases, it is quite important for SHM researchers to have a platform for convenient database access and signal processing. This paper presents an integrated SHM data management system equipped with an MATLAB interface to MySQL database so that researchers can get access to the database and perform signal processing and analysis in MATLAB. The SHM data management system has also web-interfaces to show time histories of raw measurements and derived quantities showing an overview of the data sets.

2 SHEFFIELD SHM DATA MANAGEMENT SYSTEM

An overview of the Sheffield SHM data management System is shown in Figure 1. There are three key components of the system: a MySQL database, a MATLAB interface and a web interface. Sensor measurements taken at each structure are inserted into a site database server or saved into a raw measurement file in a remote PC. Then the site database is replicated into the Sheffield SHM Database (SSDB) or raw measurement files are transferred to Sheffield SHM Server and inserted into the database. MATLAB scripts run signal processing periodically and analysis on new and historical data obtained from the database and saves processed results back into the database. Reading and writing data from/to the database is carried out by a MATLAB class "shmYm" and a MATLAB wapper "mYm connector" described in the following Section. Using the "shmYm", a SHM researcher can read any data in the SSDB and load into the MATLAB workspace on an Internet enabled PC. The remote accessibility makes it possible for international researchers to collaborative over the Internet. The web interface provides an easy way to see time histories and scatter pots for any

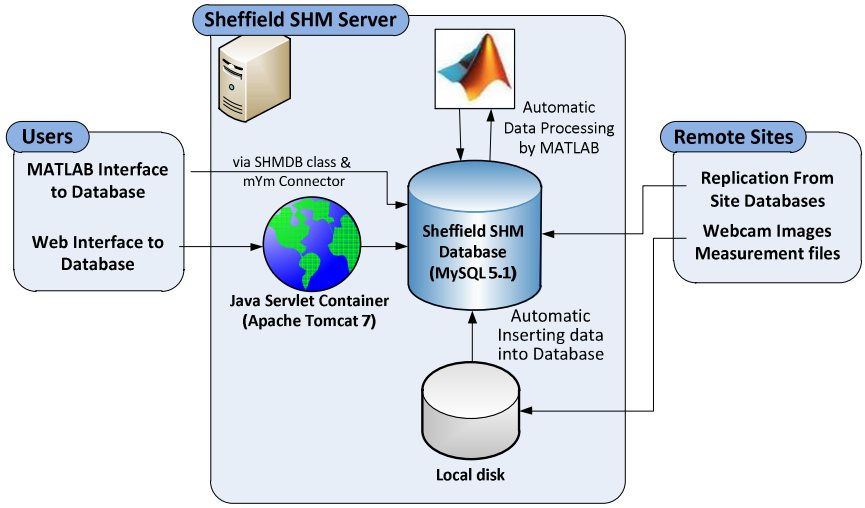

Figure 1. Organization of Sheffield SHM Data Management System.

channels over a user selected time window. It is useful to provide an overview of the available data sets to the users.

2.1 MySQL Relational Database Management System (RDBMS)

MySQL is one of the most popular database management systems currently in use. MySQL focuses on the features most people need. In other words, MySQL has fewer

features than the other competitors, but has a small-sized and faster implementation being able to run modest desktop systems. It is easy to install without a lot of difficult and sophisticated configuration which is attractive to beginners of RDBMS. Also, MySQL is easy to build interfaces to other software written in C, PHP, Perl, Python, Ruby, and Microsoft .NET languages (Tahaghoghi and Williams 2007). For aspect of licensing, MySQL is an open-source code project under the terms of the GNU General Public License (GPL) which means it is free to use under the GPL license (MySQL-AB 2011).

2.2 MATLAB Interface

It is highly required for SHM researchers to have a MATLAB interface to MySQL databases as MATLAB is the most popular signal processing and research platform due to the state-of-the art toolboxes.

The first choice can be the MATLAB database toolbox which provides access to virtually every database engine including MySQL. However, the database toolbox requires additional license of the toolbox.

An alternative is to use an open-source code mYm which is a MATLAB interface to MySQL database written in C++ to produce a MATLAB MEX function[1] invoked by MATLAB command window (mYm-Wrapper-for-MATLAB 2011). mYm enables a MATLAB user to use Structured Query Language (SQL) which is a standard language to manipulate contents of RDBMS. However, requirements of SQL knowledge may cause a difficulty for non-IT back-grounded researchers.

A MATLAB class shmYm is developed based on mYm by the author to provide easy-to-use functions not requiring any SQL knowledge. The class provides a few functions extremely intuitive to use: read, write, etc. with input arguments of a table name, column names, and time window. The MATLAB class shmYm can be regarded as a general template. For a specific structure, a sub-class can be created by inheriting the superclass shmYm. Following MATLAB commands depicts how simple reading database is for Tamar Bridge Database.

```
% Usage Example of MATLAB Interface
% MATLAB Commands showing how to reading and plot SHM data
from Tamar Bridge Database

% tamar_bridge_db is a subclass created by inheriting shmYm
class
tbdb = tamar_bridge_db;
table_name = 'summary'; % specify name of table to read
column_name       ={'temperature_deck','extension_south'};%
specify columns of the table
time_window           =           [datenum(2011,1,1,0,0,0)
datenum(2011,1,8,0,0,0)]; % specify a time window
```

[1] MEX stands for MATLAB Executable. A MEX function is a executable subroutine written in C, C++ or Fortran which must be compiled according to MATLAB specifications before use.

```
[timestamp, data, columns] =
read(tbdb,table_name,column_name,time_window) % READ
plot(timestamp, data);
datetick('x','keeplimits'); % Convert MATLAB date numbers
to human readable strings
```

2.3 Web Interface

The web interface provides two ways of visualizing SHM measurement data: 1) Online panel for displaying time-histories of several pre-selected channels for a user-selectable time-window and 2) Interrogator in which the user browses a list of all channels available and can select channels to show time histories and scatter plots as shown Figure 5.

The visualization code has been written in JavaScript using Google Chart Tools API[2] which interacts with the Google SQL-DataSource Servlet[3] running on the Java Servlet Container[4] (Apache Tomcat 7) in the Sheffield SHM Server. The visualization code is based on AJAX (Asynchronous JavaScript and XML) which can lower the server-side loads and waiting times on the client-side.

3 APPLICATIONS

The SHM data management system is currently operating for three structures in UK: 1) Tamar Bridge, Plymouth, 2) Humber Bridge, Hull and 3) Arts Tower, Sheffield. The two bridges are introduced in this section.

3.1 Tamar Bridge

The Tamar Bridge (Figure 2) forms a vital transport link over the River Tamar carrying the A38 trunk road from Saltash in Cornwall to the city of Plymouth in Devon. Tamar Bridge has been re-strengthened 2000 by adding 18 additional stay cables, two cantilevers on both side of the bridge, and replacing the heavy concrete-slab deck with lightweight orthotropic steel deck. During the upgrade, Fugro monitoring system has been installed to monitor bridge integrity during and after the upgrade. Vibration Engineering Section (VES), University of Sheffield has added more sensor systems such as accelerometers, extensometers at the expansion joint, and a robotic total station as shown in Figure 3.

A Tamar Bridge database diagram is shown in Figure 4. Web interface of Tamar Bridge Database is shown in Figure 5.

[2] API: Application Programming Interface
[3] Servlet: a small, server-resident program that typically runs automatically in response to user request.
[4] Java Servlet Container: a web server that interacts with servlets written in Java Language

Figure 2. Tamar Bridge, Plymouth, UK.

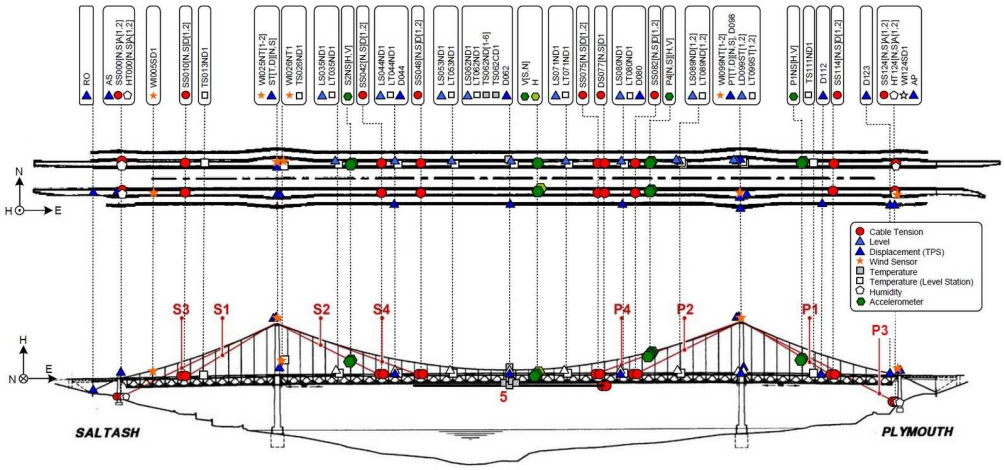

Figure 3. Sensors in Tamar Bridge.

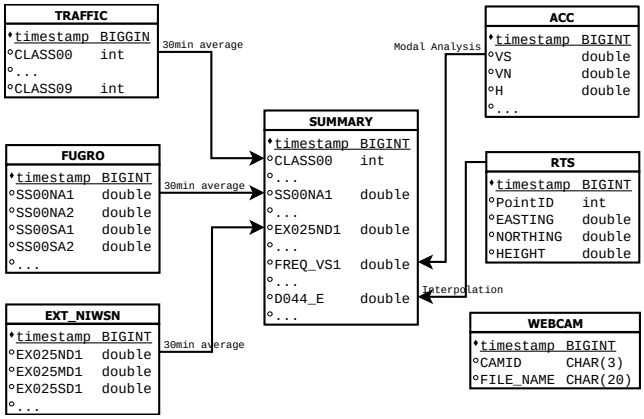

Figure 4. Database tables and columns of Tamar Bridge Database.

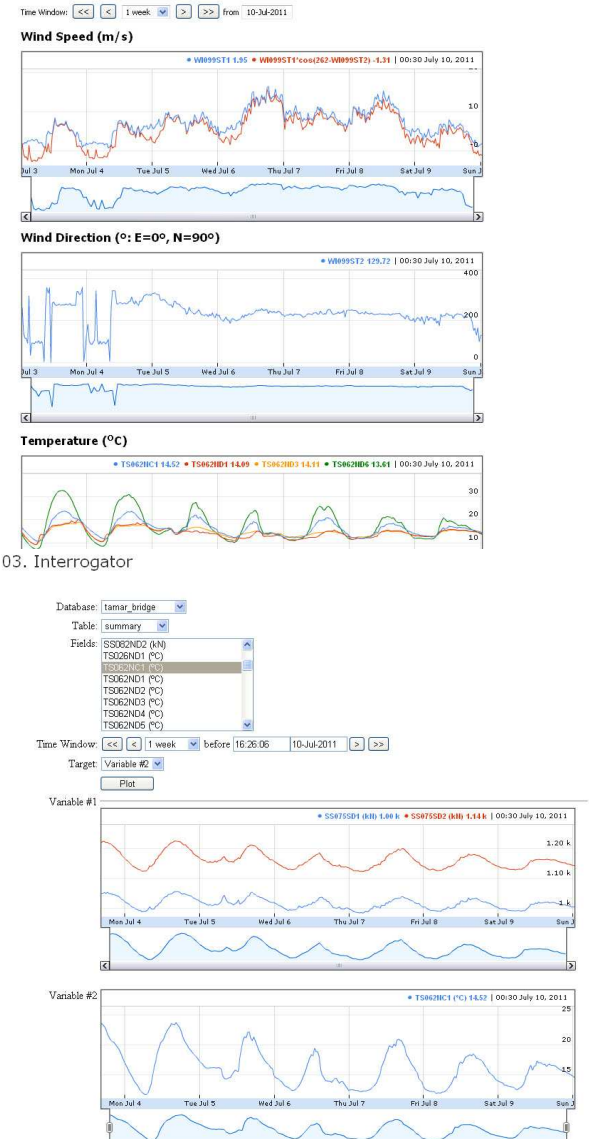

Figure 5. Screenshot of Tamar Web Interface: (left) Online page, (right) Interrogator page.

3.2 Humber Bridge

The Humber Bridge (Figure 6), which was opened in July 1981, has a main span of 1410 m with side spans of 280 m and 530 m. After Severn and Bosporus Bridges, Humber was the third bridge designed by Freeman Fox and Partners having aerodynamic steel box decks and inclined hangers. The spans comprise 124 units of 18.1 m long 4.5 m deep prefabricated sections 28.5 m wide, including two 3 m walkways. The top of each box section constitutes an orthotropic plate on which mastic asphalt surfacing is laid, and the sections have four internal bulkheads. At the ends of each span are pairs of A-frame rocker bearings that provide restraint in three degrees of freedom.

Sensors installed at Humber Bridge are explained in Figure 7. Four extensometers are measuring main-span extensions from the tower locations. Two GPS units are

measuring 3D movements of mid-span main-cable. Accelerations and inclinations are also measured at the mid-span. Database diagram of the Humber Bridge database is shown in Figure 8. Screenshots of Web Interfaces are shown in Figure 9.

Figure 6. Humber Bridge, Hull, UK.

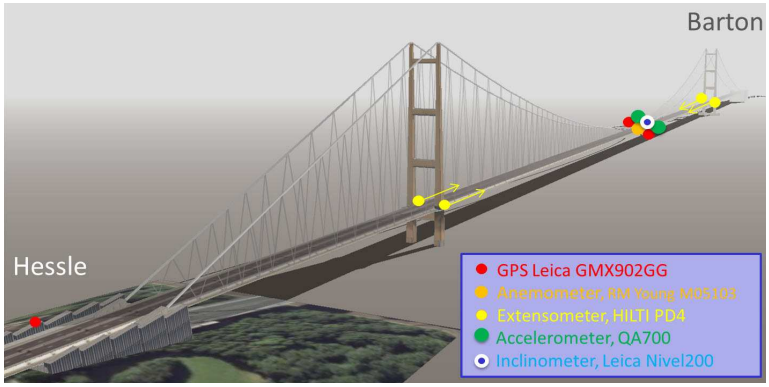

Figure 7. Sensors in Humber Bridge.

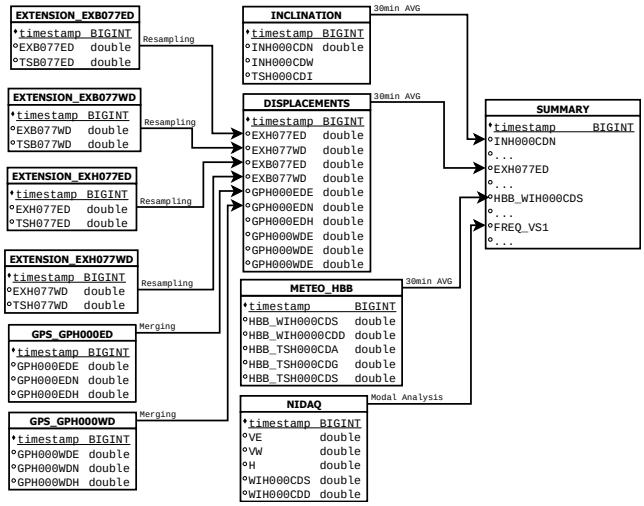

Figure 8. Database tables and columns of Humber Bridge Database.

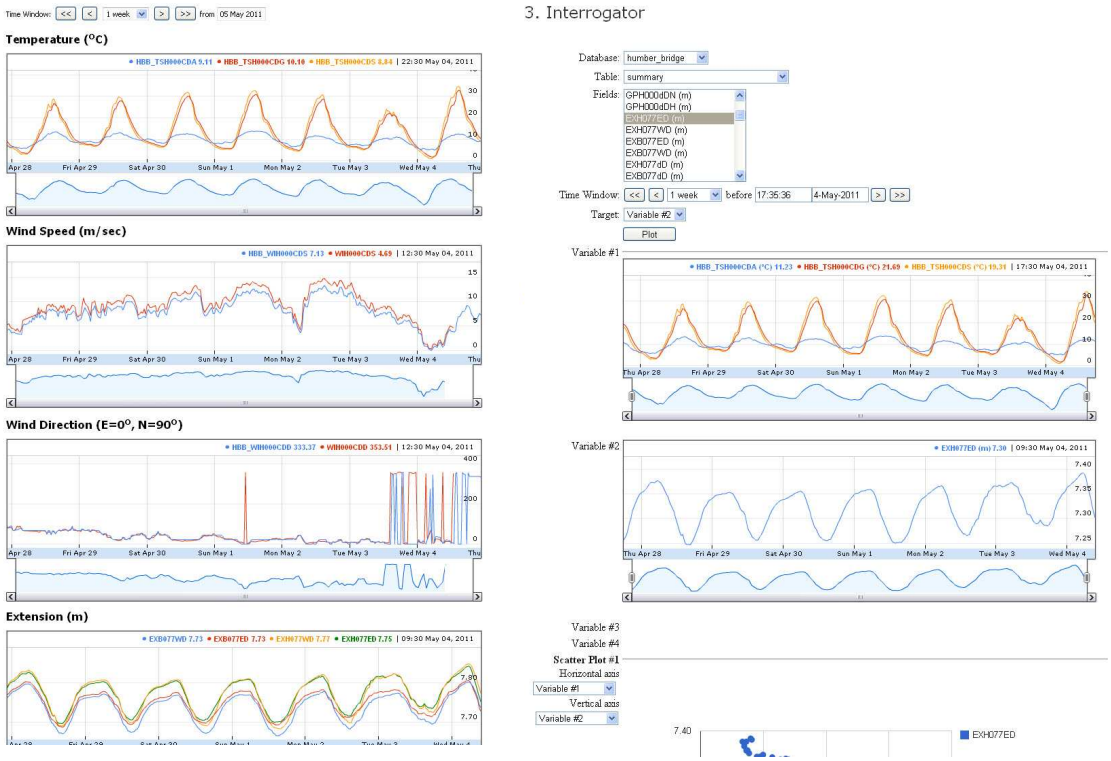

Figure 9. Screenshot of Humber Web Interface: (left) Online page, (right) Interrogator page.

4 CONCLUSION

This paper presented the Sheffield SHM data management system (SSDMS) which has been used to store SHM measurements from Tamar Bridge, Humber Bridge and Arts Tower. The SSDMS provides the MATLAB interface for researchers to get access to the vast measurement data sets easily and instantly from their MATLAB workspace. The MATLAB interface is important to support knowledge discovery from the database since MATLAB is one of the frequency used signal processing and research platforms. SSDMS has Web interfaces for instant visualization of measurement data.

The SSDMS needs to be evolved into a better complex system to cover all the relevant SHM information including details of design, construction, and maintenance in order to support active collaborations and knowledge discovery between structural designers, operators, and SHM researchers.

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