Wireless Data Acquisition from Bridge Monitoring

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Abstract—This paper introduces composition of a system platform to collect data from a wireless monitoring bridge, develops software to receive data from monitoring bridge fixed with vibration sensors and temperature sensors. We use INV3020 made by Coinv(China Orient Institute of Noise & Vibration) as a lower-position machine. Communication protocols between INV3020 and upper-position machines have been defined during data acquisition of INV3020 and computers in a laboratory. Developed software with C sharp in the upper-position machine by the communication protocols enables to decode vibration and temperature signals collected by INV3020 and save them into database created by SQL Server. The upper-position machine can also control some actions of INV3020 regarding how to collect data and when to send time-domain waveform. 3D GIS is used to show locations and status of sensors. There is a model library in the upper-position machine that can set limen to judge if the bridge works well. Research shows that INV3020 is an excellent product to monitor bridges, our developed software is a good try to receive data from monitoring bridge.

Keywords-3D-GIS;bridge monitoring; sensor;data aquisition; time-domain waveform

I. INTRODUCTION

Due to the absence of checking and monitoring the structure of bridges, people cannot know if a bridge works well. Accordingly, bridge collapse happens frequently, which makes it increasingly important to routinely check and monitor the bridge structure. Humen Bridge in China has adopted GPS and optical fiber data transmission system for dynamic and real-time bridge monitoring at a monitor center [1]. All bridges on the river of Winooski in Vermont, USA, have fixed monitoring system mainly based on optical fiber sensors [2]. Integration techniques to monitor bridge health [3] and three-dimensional GIS platform for real-time bridge monitoring [4-5] are also being developed in China.

The collected and analyzed information from monitored bridges can supplement and/or revise the existing bridge design standards. In addition, the structural health monitoring system can be used as a warning system that can detect the abnormal behavior[6]. Based on three-dimensional GIS, this paper reported a research to get data in laboratory from a monitoring bridge.

II. COMPOSITION OF THE SYSTEM PLATFORM

Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit-mapped fonts if possible. True-Type 1 or Open Type fonts are preferred. Please embed symbol fonts, as well, for math, etc.

The system consists of a lower-position machine, the sensors,Data Transfer Unit(DTU), communication network, and upper-position machine (See Fig .1). The lower-position machine INV3020, an industrial personal computer, was made by China Oriental Institute of

Noise & Vibration (COINV). Designed in accordance with industry standard of Compact Peripheral Component Interconnect, INV3020 has 16 channels, a chassis, a computer module, and several data acquisition cards. The lower-position machine is quakeproof, has good ventilation performance, and can sustain in harsh field working environment.

With the vibration sensors and temperature sensors connected to the bridge, this machine is able to collect the real-time data of vibration and temperature for a bridge. The data collected by the lower-position machine is then transformed to TCP/IP packets by DTU for transmission. Software to sample bridge is developed by COINV according to defined communication protocol.

The upper-position machine, which is a normal computer in a laboratory, uses the Client/Server mode, calls the 3D GIS controls of Skyline by VS2008 and displays the working state of the bridges and sensors. Then according to the communication protocols, the upper-position machine decodes the data sent by the lower machine and saves it in the SQL Server database. Based on the analysis of the data, the upper machine can determine the status of the bridge and make early warning of the problems that may occur in the usage of the bridge.
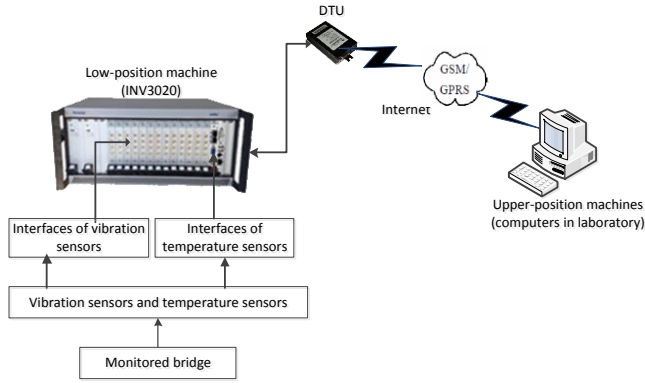
Figure 1. Composition of the bridge monitoring system

A.   *Temperature sensors*

SBWZ-K Temperature Instrument (see Fig .2) is mainly responsible for collecting real-time temperature information. Micro-signal acquired from temperature sensor is amplified to 4~20mA standard signal and pass it into regional controller that can convert all the collected standard current signal to a standard protocol package 485 output signal. SBWZ-K temperature sensor is two-wire transmission mode (power input and signal output share two common wire).

Figure 2. Temperature sensor(left) and Vibration sensor

B.   *Vibration sensors*

To monitor bridge vibration, INV9828 acceleration transducers made by COINV are used. INV9828 is good at low noise, high resolution and high sensitivity. It can work between -20℃～+120℃ 。

III.   COMMUNICATION PROTOCOL

In order to keep the normal communication between the upper-position machine and the lower-position machine, this project develops the communication protocols according to the actual situation. The communication information uses two formats: decimal format and binary format. When transmitting the time-domain data, binary format is used. Besides that, all the information uses decimal format. The protocols have defined the format, by which the lower-position machine sends the information to the upper-position machine, including dynamic measurement signal eigenvalue, temperature signal eigenvalue, vertical direction modal analysis data, horizontal direction modal analysis data, sensor sampling information; sensors work status, channel alarm information, time-domain waveform, etc. The protocols have also defined the format, by which the upper-position machine controls the lower-position machine, including setting the channel threshold, setting the sampling frequency, setting the sampling time interval, re-sending the eigenvalue, sending the time-domain waveform, etc.

All information received from the lower-position machine begins with "$" and ends with "!". A character follows after "$" to show what information and order it is. Other characters between "$" and "!" contain the details of the information.   Below   are   two   examples   for communication protocols:

A.   *The order format for receiving dynamic measurement signal eigenvalue is:*

$Pn,X1,X2,X3,X4, X5, X6!

P: an order to send a dynamic measurement signal eigenvalue;

n: the number of channel;

X1:mean value;

X2: maximum value;

X3: minimum value;

X4: quadratic mean deviation;

X5: valid value;

X6: peak-peak value, X6=X2-X3

B.   *The order format for receiving a vertical direction modal analysis is:*

$Zn,Freq,Damp,Shape1,Phase1,Shape2,Phase2,……,ShapeN, PhaseN!

Z: an order to send a vertical direction modal analysis;

n: order number of modal number(integer);

Freq: modal frequency (float);

Damp: modal damping (float);

Shape1:vibration amplitude of No.1 node(float);

Phase1:vibration phase of No.1 node(float);

ShapeN:vibration amplitude of No.N node(float);

PhaseN:vibration phase of No.N node(float);

IV.   THE REALIZATION OF THE 3D-GIS SYSTEM IN THE UPPER-POSITION MACHINE

The upper-position machine calls the API provided by the TerraExplorer to access the three-dimensional GIS geospatial data in the .net environment by C# [7-8]. Then the upper-machine uses the ActiveX controls provided by TerraExplorer to display the three-dimensional bridge model in the 3D window [7]. Fig .3 is the workflow chart of the upper-position machine.
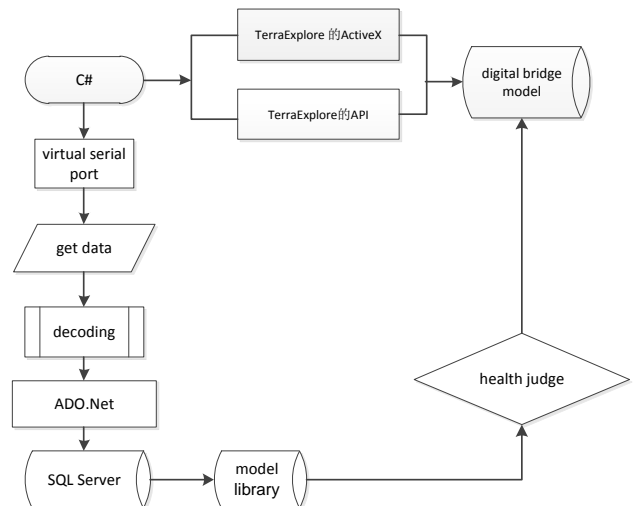

Figure 3. Working flow chart of upper-position machine

A. Establishment of the Database

Based on the communication protocol, the upper-position machine receives the data from the Internet. The data is then translated, and stored in the SQL Server database. What is stored includes the dynamic measurement signal eigenvalue, temperature eigenvalue, vertical modal analysis data, horizontal direction modal analysis data, sampling data, channel alarm data, anomaly data of sensors, etc.

B. Building the Digital Three-Dimensional Model of the Bridge

3DSMAX is a 3D modeling software widely used on PC; this project used it to create a digital bridge model. The 3D bridge model is based on the bridge that is regarded as the main object. The modeling uses the way of polygon modeling. After being built, the model should be converted to generate *.x first. Then this project used other software to generate the three-dimensional terrain file *.mpt (see Fig .4). At last, TerraExplorer loads the *.mpt file, saves it, and generates a fly project, which can be called by C# [7].
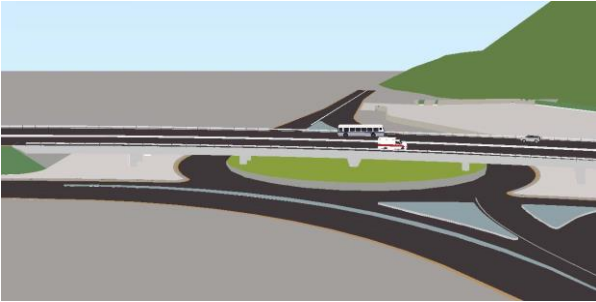

Figure 4. Digital bridge model

We can use these C# codes to call a fly project named "default.fly" :

```
 private                string               flypath
=Application.StartupPath+@"\default.fly";
    private TerraExplorer TE;
    private ITerraExplorer5 objTerraExplorer5;
    private IInformationTree5 objInformationTree5;
………
private void FrmMain_Load(object sender, EventArgs e)
{
……
objTerraExplorer5.Load(flypath);
……
}
```

The sensors attached to the bridge can be implemented by modeling. This paper denotes sensors as "Text Lable" in TerraExplorer to increase flexibility. According to the coordinates of these sensors recorded in database, C# would call the API of TerraExplorer and place them automatically on the bridge [8].

C. The Realization of the Serial Communication Technology

The communication is mainly completed by the SerialPort class provided by C#. It uses decimal transmission except time-domain waveform, for which it uses binary transmission. Thus, there are two scenarios in which the serial communication technology can be realized.

Obtaining the Decimal Data

The BytesToRead method in SerialPort class is used to read the bytes from the serial ports and transform it into the hexadecimal string using the regular expressions according to the communication protocols [11]. Then the appropriate information is extracted and stored into the corresponding table of the database. Fig .5 is the user interface to receive data from INV3020.
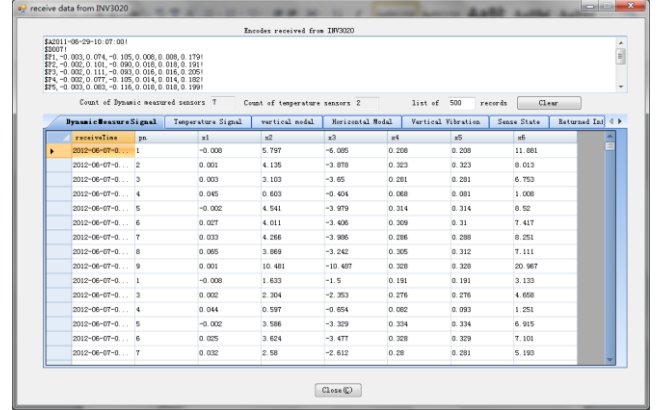

Figure 5. Receiving data from INV3020

We can realize it with C# codes:

```
private int mm = 0;
private void serialPort1_DataReceived(object sender,
System.IO.Ports.SerialDataReceivedEventArgs e)
 {
int DataLength = serialPort1.BytesToRead;//receive bytes
from buffers
int j = serialPort1.Read(acceptByte, mm, DataLength);
    mm += j;
……
}
```

We can identify dynamic measurement signal eigenvalue with C# codes:

```
 public void DynamicCode(string codeString, string
sendTimeString)
 {
string  reDynamic  =  "(\\$P\\d{1,3})(,\\-?([0-9]*)(\\.[0-
9]+))+";// regular expressions for dynamic measurement
signal
   string signalStrCount = "\\$D\\d{3}";//to get the channel
count
   MatchCollection  mc2  =  Regex.Matches(codeString,
reDynamic);
   MatchCollection  mc3  =  Regex.Matches(codeString,
signalStrCount);
   if                                  (mc2.Count
==int.Parse( mc3[0].ToString().Substring(2, 3)))
   {
   int                 sCount                 =
Convert.ToInt16(mc3[0].ToString().Substring(2, 3));
    string[] measureValue = new string[sCount];
    for (int i = 0; i < sCount; i++)
   {
    measureValue = Regex.Split(mc2[i].ToString(), ",");
```

```
    try
    { //save data to database
saveDB.DynamicSignalInsert(sendTimeString,
Convert.ToInt16(measureValue[0].Substring(2)),
Convert.ToDouble(measureValue[1]),
Convert.ToDouble(measureValue[2]),
Convert.ToDouble(measureValue[3]),
Convert.ToDouble(measureValue[4]),
Convert.ToDouble(measureValue[5]),
Convert.ToDouble(measureValue[6]));
    }
        catch (Exception ex)
            {
                ……
                continue;
            }
        }
    }
}
```

Obtaining the Binary Data

Only when the lower-position machine INV3020 receives the time-domain waveform command from the upper-position machine will it send the time-domain waveform data. The difference in the method of reading the time-domain wave from the eigenvalue is: when the time-domain waveform data is large, the system would divide it into several data packets for transmission. As a result, it is possible to lose data packets when transmitting them. Because the communication line is GPRS, INV3020 cannot determine whether the packet is lost, so the upper computer should judge whether the packet is lost by the information on the start and end points of each packet.

D. Setting of the Bridge-Warning Value

Bridge monitoring would generate huge amounts of data. How to use and analyze the data to judge the health status of the bridge is a tough task in bridge health diagnosis. The most promising method recognized commonly is an experimental model method combining interdisciplinary technologies including system identification, vibration theory, vibration testing technique, signal acquisition and analysis.

The system attempts to build the different kinds of model library of modal frequency. Users can take the advantage of the level and vertical modal analysis historical data (including modal frequencies, damping, amplitude, etc.) from the lower-position machine. Then the system makes numerical simulation of the modal frequencies in different periods and temperatures of the bridge. The result of the simulation would be used to modify the relevant parameters in the model library. Then the system compares the actual measured modal frequencies and the frequencies calculated by the modified model, the result would be used as a warning threshold.

V. CONCLUSION

This paper tries to collect monitoring bridge data with INV3020 as lower-position machine and GPRS as a means of communication. Our software realizes the real-time dynamic bridge monitoring based on 3D-GIS technique. Computers in a laboratory enable to get the vibration and temperature information of the bridge and control the lower-machine by means of control command. With 3D-GIS technique, the upper-position machine can display three-dimensionally the work state of the bridge and sensors, builds the bridge alarm model library and explores the way to set the alarm value for the bridge.

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