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REMOTE BRIDGE MONITORING SYSTEM WITH OPTICAL FIBER SENSORS

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SUMMARY

By utilizing the inherent traits of optical fiber sensors, the conventional monitoring strategy can be extended from the form of individual points to networks. Although the optical-fiber-sensor-based system has shown their prominent advantages over the last few years, however, the measurement task could only be executed on site, ie, the automatically real-time long-term monitoring may not be executed under the current system architecture. In order to improve the performance of current system, integration of the remote-sensing function into the current system is needed. To implement this concept, several types of remote bridge monitoring systems are evaluated in this paper.

The application of three different techniques including General Packet Radio Services, (GPRS), wireless transmission, and asymmetrical digital subscriber line (ADSL) were appraised thoroughly with a simulated environment in National Center of Research on Earthquake Engineering. (NCREE) With the help of these methods, the measurement distance of the monitoring system can be extended to hundreds of kilometers. The evaluation result has shown that the case with the combination of ASDL system and wireless transmission is fastest one for offering a reliable data conveyance rate while the GPRS system offers the most economic and robust service. Both of the two system can be easily incorporated into the original surveillance system and largely enhance their performance. The integrated system with the remote-control ability can expected to be applied to any existing bridge under harsh environment in the near future.

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INTRODUCTION

The development of fiber optics, barely out of its infancy as a valuable commercial enterprise, has been seeing stunning technological advances over the last few decades. Concurrently, the fiber optics industry accounts for one-sixth of the U.S. economy and is playing an increasingly important role in the telecommunication field. Together with the development of fiber optical communications, another research field, optical fiber sensing, has also been developed during the last few decades to give optimum sensitivity in measuring local activation. Meanwhile, recent researches as smart structures also point out the need for dense arrays of such stress-strain meters and their future, hence, appears to be conditioned by the development of very broad-range sensors, which are low cost and easy to install as dense arrays. Potentially, optical fiber sensors could be a solution for the increasing demand in having reliable strain sensors since they allow remote sensing and high networking capability. Advancements in the field of opto-electronics have made new instruments available at even lower costs and with improved durability and compactness, allowing on-field applications.

Among the large number of sensors developed recently for strain monitoring, FBG sensors appear to be the most promising for reliable applications. The main advantages of these Bragg-grating based strain sensors are their low cost, permitting easy implementation of large arrays covering a very wide frequency range from static to thousands of Hz.

A simple description of the FBG measurement theory is shown in Figure 1. Specified wavelengths of the input light source can be reflected by FBG sensors and received by the detector. Designate data can then be converted from the wavelength shift of the reflective signal, proportional to the strain induced by either loads or temperature change.

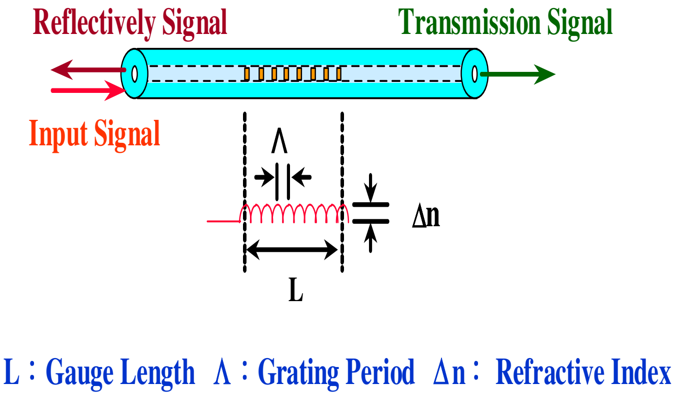


Figure 1 Measurement theory of FBG sensors

The relationship between the change in the wavelength λ_B of the reflective signal for each FBG sensor and the corresponding strain data can be expressed as

$$\frac{\Delta\lambda_B}{\lambda_B} = (1-P_e)\varepsilon = K_e\varepsilon \qquad \text{……………………..………………………(1)}$$

where ε is the strain induced to the sensor, K_e is the strain sensitive coefficient, and P_e is the photo-elastic constant as following.

$$P_e = \left[\frac{n^2}{2}\right]\left[P_{12} - \nu\left(P_{11} + P_{12}\right)\right] \qquad \text{……….…………………………….(2)}$$

where P_{11} and P_{22} are the strain tensor of optical fiber, n is the effective refractive ration , and ν is the Poisson ratio of optical fiber.

The reflective wavelength of FBG sensors is also influenced by temperature change and the relationship between temperature change and wavelength shift can be expressed as

$$\frac{\Delta\lambda_B}{\lambda_B} = (\xi + \alpha)\Delta T = K_t \Delta T \qquad \text{……………………………………… (3)}$$

where ξ is the thermal optical coefficient, α is the thermal expansion coefficient and K_t is the temperature sensitive coefficient.

Currently, FBG sensors have been successfully applied for the instrumentation of civil engineering structures as well as optical filters in fiber communication area. Several studies have examined the static and long-term instrumentation in civil engineering structures using FBG sensors [1]. FBG sensors have also been designed and used to measure dynamic deformations in rock masses and strain variations in the range of 10-9 with a bandwidth of 0.1-2 KHz, and results have been compared with respect to conventional methods [2]. Furthermore, experimental field trials have been carried out showing that the grating sensor systems can be operated into harsh working environments. For example, special steel rock bolts using FBG sensors have been designed to measure relative strain [3]. Moreover, there is also research on applying novel sensor elements for long-term surveillance of tunnels based on FBG sensors [4]. Twenty Bragg gratings were also embedded into concrete girders used to support a bridge deck in Calgary, Canada. All these results have demonstrated the outstanding performance of FBG sensors in civil engineering.

Accompanying by the success of FBG sensors in civil engineering, researchers have attempted to extend the optical-fiber-based monitoring system into the existing optical fiber networks. The measured information would be transferred in light speed with a reliable quality and the integrated system could offer the warning signal before any serious damage. Therefore, the life and properties of human beings could be covered against any unexpected disasters. For this reason, a prototype of remote bridge monitoring system is established in this paper. The optical fiber monitoring system built by the research team in the past few years will be integrated with different remote transmission technologies and the result will be compared and discussed.

REMOTE BRIDGE MONITORING SYSTEM

Recently, by the prosperous development of internet, the integration between internet and research has become prevailing. Moreover, the rising of broadband network has also made worldwide data communication feasible. For these reasons, the digitized remote monitoring system has become an inevitable trend in the past few years.

Conventionally, the remote monitoring system is built on the basis of telephone line and the monitoring instrument can only be manipulated on site. However, with the popularity of the broadband internet, the real-time remote monitoring system has been proved for its possibility. The concept of remote monitoring is shown in Figure 2.

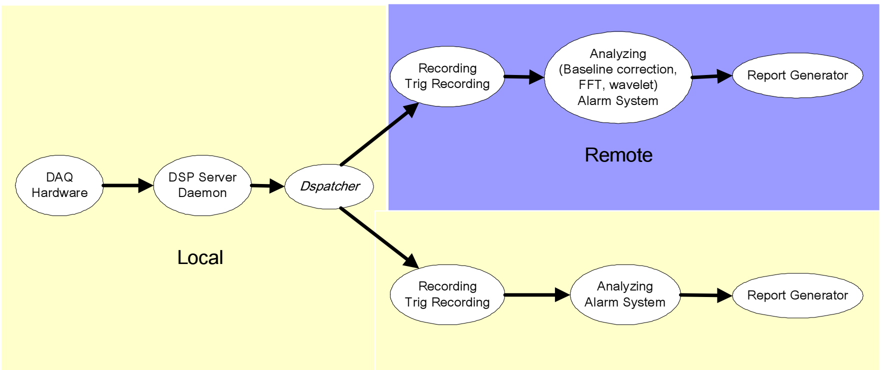


Figure 2 Concept of remote monitoring system

Upon the technology developed for remote bridge monitoring system, there are three different suitable solutions, which is the wireless, GPRS, and ADSL system. For the system conformation and development potential of this remote bridge monitoring system, which will be executed on site, these three solutions are evaluated in the laboratory to establish a remote monitoring system. A simple comparison between these tree methods is listed in Table 1 and the theory of these three methods is briefly described as follows:

Table 1 Comparison between three solutions

	GPRS	Wireless	Ethernet Sever
Transfer method	wireless	wireless-WAN	WAN
Transfer speed	slow	high	high
Transfer cost	low	low	low
Transfer quality	medium	high	high
convenience	high	high	low

Wireless Solution

The wireless solution built here combines both the wireless and Ethernet communication in the system. By using a 2.4GHz wireless module, the measured data are transferred to a local server to overcome the tough working environment. These data are then communicated with the monitoring center by the Ethernet. The advantage of using this solution is that the wireless part can overcome the harsh environment obstacle up to 500 meters around the monitoring site. For choosing a suitable location of local server, this solution would be the easiest one among the candidates.

The process of this solution is shown as:

1. Save the monitoring data to the local computer.
2. Upload the data to the local server by the wireless module.
3. Communicate the data between the local server and monitoring center by the FTP protocol.
4. Broadcast the monitoring result on the internet by the web-based method.

Ethernet Solution

By deploying the Ethernet to the local site, the Ethernet solution can offer the fastest speed for real-time monitoring. However, the difficulty in maintaining the physical line would be the biggest problem in this solution. The monitoring system can be easily crashed by any break point through the whole line. Therefore, the protection of the Ethernet on site would be the most important issue of this solution.

The process of this solution is shown as:

1. Save the monitoring data to the local computer.
2. Upload the data to the local server by the Ethernet.
3. Communicate the data between the local server and monitoring center by the FTP protocol.
4. Broadcast the monitoring result on the internet by the web-based method.

GPRS Solution

With the development of mobile phone industry, the application of GPRS system has also matured in the past few years. The current GPRS communication rate is listed in Table 2. By using the GPRS system, the remote monitoring system can send the record to the internet wirelessly. The monitoring center could then obtain the data directly from the internet. Due to the wireless form of the GPRS solution, the transfer rate would be much slower than the Ethernet solution. However, the mobility would be the major concern about the GPRS solution. The system can be easily implemented by a simple GPRS module without lots of space. Moreover, the limited bandwidth would also be sufficient for the long-term bridge monitoring process.

Table 2. Classification of GPRS communication

Channel code classification	Transfer rate per channel (Kbit/sec)	Maximum transfer rate (Kbit/sec)	stability
CS-1	9.05	9.05*8 =72.4	high
CS-2	13.4	13.4*8=107.2	medium
CS-3	15.6	15.6*8=124.8	medium
CS-4	21.4	21.4*8=171.2	low

The process of this solution is shown as:

1. Save the monitoring data to the local computer.
2. Upload the data to the GPRS module via RS232.
3. Upload the data to the internet.
4. Download the data to the GPRS receiver.
5. Download the data from the GPRS receiver via RS232.
6. Communicate the data to the local server.
7. Broadcast the monitoring result on the internet by the web-based method.

VERIFICATION OF THE FBG-GPRS SYSTEM

After evaluating these three solutions for their feasibility in the practical bridge monitoring project, the GPRS solution is chosen to be the most suitable one. The FBG-GPRS system is then built and tested for its performance in next generation monitoring system. The structure of the proposed FBG-GPRS system is shown in Figure 3.

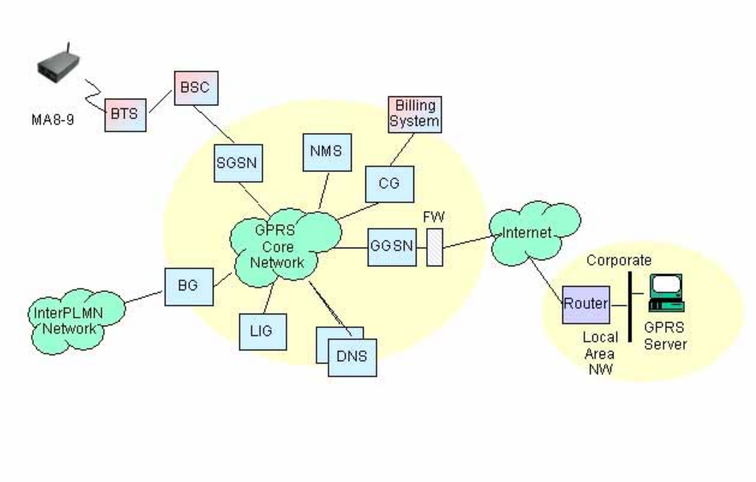
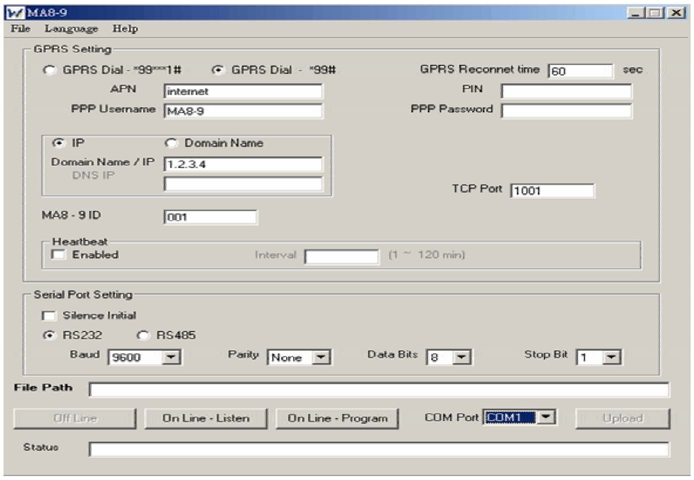


Figure 3 structure of the FBG-GPRS system

The GPRS module MA8-9, shown in the up-left corner of the structure, is detailed in Figure 4. The module communicates in the rate of Packet switch data (GPRS3+1) and transfers the data to the computer through the RS232 port. A typical set-up screen for the MA8-9 is also shown in Figure 5.

Figure 4 The GPRS module MA8-9



GPRS Setting

○ GPRS Dial - *99***1#   ● GPRS Dial - *99#

GPRS Reconnet time 60 sec

APN internet

PIN

PPP Username MA8-9

PPP Password

● IP   ○ Domain Name

Domain Name / IP 1.2.3.4

DNS IP

TCP Port 1001

MA8 - 9 ID 001

Heartbeat

☐ Enabled   Interval   (1 ~ 120 min)

Serial Port Setting

☐ Silence Initial

● RS232   ○ RS485

Baud 9600   Parity None   Data Bits 8   Stop Bit 1

File Path

COM Port COM1

Status

Figure 5 Typical set-up screen for the MA8-9

The FBG-GPRS system is then tested for its stability in the laboratory. By the limited bandwidth of GPRS communication, the stable refreshing rate for the data transfer would be once per three seconds. The record could be received without any loss under this sampling rate. The communication result with on e FBG sensor is shown in Figure 6. The left-hand side is the on-site monitoring result and the right-hand side is the data received from the monitoring center. It is seen that the trend is compatible and no noise is contained during the communication. The monitoring distance could be extended hundreds of kilometers by the system.

Moreover, the FBG-GPRS system is also verified by transferring multiple-channel data. Four FBG sensors are connected to the instrument and the recorded data are transferred to the remote monitoring center. The result is shown in Figure 7. Similarly, there is no loss during the communication and the trend of the measurement in satisfying.

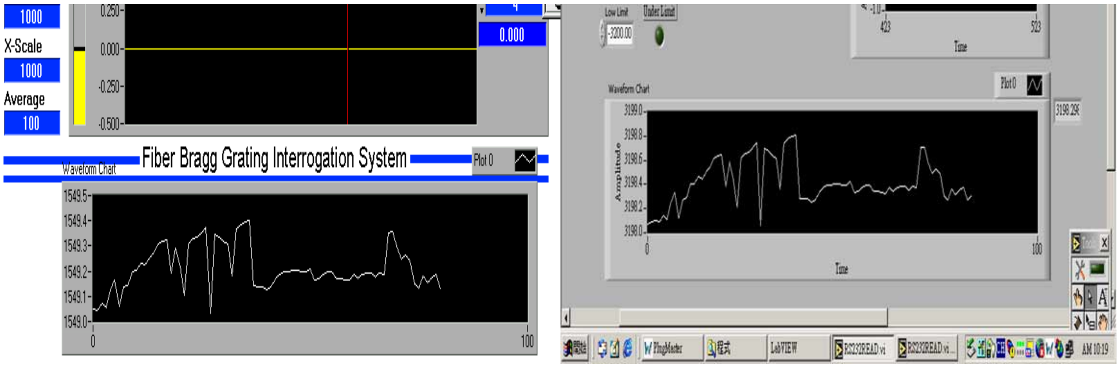
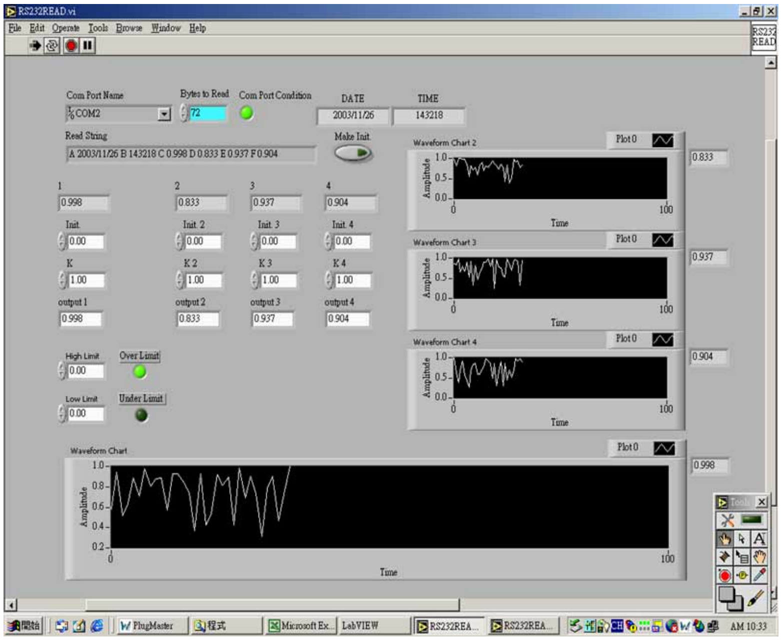


Figure 6 Communication result of the FBG-GPRS system



Com Port Name: COM2
Bytes to Read: 72
Com Port Condition
DATE: 2003/11/26
TIME: 143218
Read String: A 2003/11/26 B 143218 C 0.998 D 0.833 E 0.937 F 0.904

1	2	3	4
0.998	0.833	0.937	0.904
Init.	Init. 2	Init. 3	Init. 4
0.00	0.00	0.00	0.00
K	K 2	K 3	K 4
1.00	1.00	1.00	1.00
output 1	output 2	output 3	output 4
0.998	0.833	0.937	0.904

High Limit: 0.00
Low Limit: 0.00
0.833
0.937
0.904
0.998

Figure 7 Communication result with multiple channels

SUMMARY AND CONCLUSION

A remote bridge monitoring system has been successfully established in this paper. By the prosperity of information technology, three different methods, including the wireless, Ethernet and GPRS system, are evaluated for their feasibility in a remote monitoring system. For the reliability and mobility of data transfer, the GPRS system is picked up and integrated into a FBG-based bridge monitoring system.

The system is then established and verified for its performance in pragmatic application. The result has shown that the FBG-GPRS system can stably work under a sampling rate of 3 Hz, which is sufficient for structure long-term monitoring. All the data can be broadcasted and read out through the internet over hundreds of kilometers from the monitoring site. Unlike the fragility of the conventional surveillance system, the robustness of the FBG-based system has also offer another advantage for the new developed system. This system will be continually applied on practical monitoring task to demonstrate its superior characteristics for advanced monitoring system.

ACKNOWLEDGEMENTS

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