Validation of a large-scale wireless structural monitoring system on the Geumdang Bridge

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ABSTRACT: Structural monitoring systems designed using wireless sensors have shown the potential to serve as low-cost substitutes to traditional cabled-based monitoring systems. In this study, an academic wireless sensing unit prototype explicitly designed for structural monitoring is introduced. To validate the performance of the proposed unit, a large-scale network of over 14 wireless sensors is installed in the Geumdang Bridge, South Korea. In parallel to the wireless monitoring system, a traditional tethered structural monitoring is also installed. The acceleration response of the Geumdang Bridge is recorded by both monitoring systems during forced vibration testing. The measurement fidelity of the wireless monitoring system is shown to be sufficiently accurate for precise determination of the primary modal frequencies and operating deflection shapes of the bridge. Wireless monitoring systems employ individual clocks distributed across the network; clock synchronization performed using a centralized beacon signal is assessed. In the last phase of the field study, the wireless sensing units are programmed to process data using embedded fast Fourier transforms.

1 INTRODUCTION

In recent years, structural engineers have expressed keen interest in the adoption of wireless sensors for structural monitoring. Traditionally, structural monitoring systems have been designed using coaxial cables to transfer measurement data from sensors to centralized data repositories where the data is stored and analyzed. Unfortunately, extensive lengths of coaxial wires needed between sensors and the data repository drives the cost of these monitoring systems high. Particularly for bridges, the installation of permanent monitoring systems are even more expensive and labor intensive as a result of having to route cables in a manner that protects them from ambient weather conditions.

Numerous wireless sensing unit prototypes have been proposed by the research community for use in structural monitoring systems. For example, Straser and Kiremidjian (1998) are the first to illustrate the design of a low-cost wireless sensing unit intended for structural monitoring. Since their seminal work, others including Lynch *et al.* (2003a), Spencer *et al.* (2004), Casciati *et al.* (2003), Pei *et al.* (2005), Wang *et al.* (2005), among others, have reported their research experiences with wireless sensors for monitoring civil structures.

While extensive laboratory validation has been performed on wireless sensors, there has not been nearly as much field validation. Field validation is the only way to accurately assess the performance of wireless sensors within the complex and harsh environments posed by real civil structures. For example, Straser and Kiremidjian (1998) have validated the performance of their wireless sensing unit prototypes by installing five of them upon a 15 m span of the Alamosa Canyon Bridge located in New Mexico. Again using the Alamosa Canyon Bridge, Lynch *et al.* (2003a) have installed seven wireless sensing unit prototypes to measure the acceleration response of one bridge span during forced vibration testing. Chung *et al.* (2004) have successfully installed 3 wireless sensors upon a 30-m long steel truss pedestrian bridge located on the University of California-Irvine campus to monitor its behavior under wind loading.

In this study, a wireless sensing unit prototype proposed by Wang *et al.* (2005) is used to monitor the response of the Geumdang Bridge. The Geumdang Bridge is a concrete box girder bridge recently constructed in Icheon, South Korea. The primary objective of the study is to assess the ability of a large number of wireless sensing units to reliably monitor the behavior of the bridge during truck traffic loading. In total, 14 wireless sensing units are installed in the interior spaces of the concrete box

Figure 1. Wireless sensor deployed in the Geumdang Bridge (the unit is opened to show internal components).

girder. With a tethered structural monitoring system installed in parallel, the measurement fidelity of the wireless monitoring system will be assessed. In addition, errors in synchronization of the internal clocks contained within each wireless sensing unit will be measured. The final testing objective is to illustrate ability of the wireless sensing units to calculate the Fourier frequency spectrum of the bridge response using internal computational resources.

2 WIRELESS SENSING UNIT DESIGN

A novel wireless sensing unit that integrates the latest embedded system technologies is proposed by Wang *et al.* (2005). The hardware design of the prototype unit emphasizes measurement accuracy, long-range communication and minimal total power demand. The wireless sensing unit is not a sensor *per se*, but rather a node of a wireless data acquisition system to which traditional sensors (e.g. accelerometers, strain gages) can be interfaced.

To collect measurement data from a variety of different structural sensors, the wireless sensing unit contains a multi-channel analog-to-digital converter (ADC). With a resolution of 16-bits, the Texas Instruments ADS8341 ADC can sample data from four simultaneous sensing channels at rates as high as 100 kHz. To provide sufficient space to store up to 64,000 data points at one time, the Cypress CY62128B 128 kB static random access memory (SRAM) chip is included in the unit design.

To control the flow of data through the wireless sensing unit, the unit employs a low-power microcontroller. The 8-bit Atmel ATMega128 microcontroller is selected for integration with the unit because of its low power demand and on-chip computing resources. In addition to managing the sensing interface and wireless radio, the embedded microcontroller will also be utilized for performing local data interrogation of structural response data. Software for unit operation and embedded data processing is stored in the ATMega128’s 128 kB of read only memory (ROM).

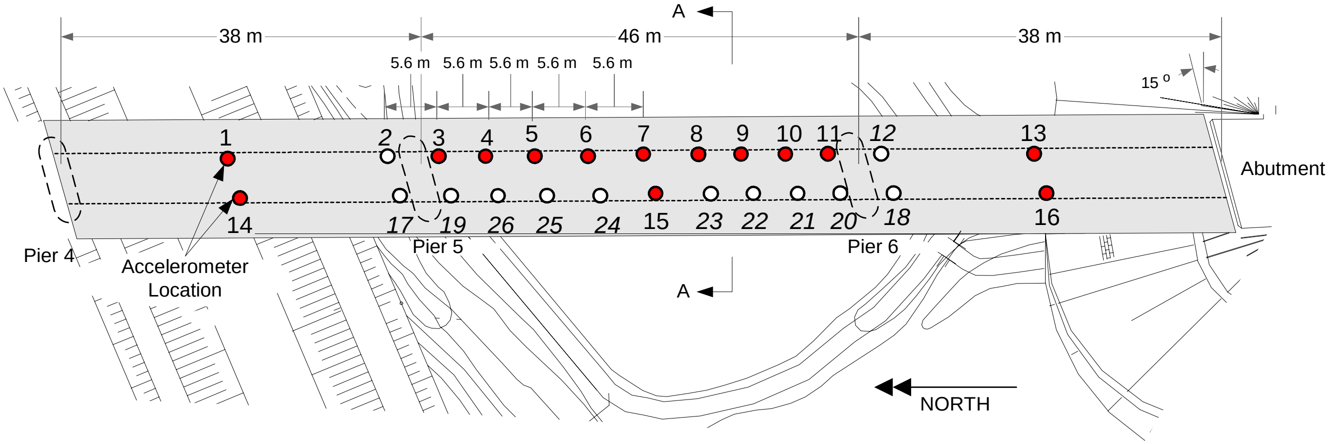
To freely transfer data between wireless sensing units and to transmit data to centralized repositories, a wireless radio with far reaching communication ranges is needed. In the design of the wireless sensing unit, the 900 MHz Maxstream 9XCite wireless modem is selected for integration. This wireless modem provides an excellent balance between low power consumption and far communication ranges. For example, the line-of-sight communication range of the XCite radio is over 300m. Meanwhile, the XCite modem only consumes 50mA of current when transmitting and 30mA when receiving data.

To achieve a compact form factor, the wireless sensing unit circuit is printed upon a two-layer circuit board whose foot print dimensions are 9.7 cm by 6 cm. To protect the circuit and battery from harsh field conditions, the wireless sensing unit is assembled within a weatherproof hardened case whose volume is less than 130 cm^3. The wireless sensing unit is powered by 5 AA batteries delivering 7.5V of electrical power. During active communication, the wireless sensing unit consumes approximately 80 mA of current; when the wireless radio is not in use, the current demand reduces to approximately 30 mA. Fig. 1 is a picture of the completed wireless sensing unit prototype that will be used in the Geumdang Bridge study.

3 GEUMDANG BRIDGE

The Korea Highway Corporation (KRC) has recently completed construction of a special 7.7 km segment of the north-south Jungbu Inland Highway near Icheon, South Korea. The intended purpose of the special highway segment is to provide a test-bed for monitoring the long-term performance of pavements and soils to truck traffic; to accomplish this task, a dense array of sub-grade sensors has been installed during construction. Along the highway length, three bridges have been designed to carry traffic over large river plains typical of the agricultural region. The Geumdang Bridge, constructed primarily from concrete pre-cast sections, is the northernmost bridge and spans 273 m. The remaining two bridges are the Yondae and Samseung Bridges which are constructed from steel sections and span 180 and 40 m, respectively. While the highway segment has been densely instrumented with an array of sensors, sensors were not installed on the bridges themselves.

The Geumdang Bridge was completed in 2002 and carries two lanes of southbound Jungbu Inland Highway traffic. The bridge is designed using two different structural system types. The northern 151 m span of the bridge is constructed from 4 pre-cast concrete I-girders that support a 27 cm concrete deck. The southern 122 m length of the Geumdang bridge is constructed from a pre-cast concrete box girder. As shown in Fig. 2, the pre-cast concrete box girder is approximately 2.6 m deep and supports a 12.6 m wide roadway. The box girder is a con-



TOP VIEW

SECTION A-A

GEUMDANG BRIDGE SIDE VIEW

Figure 2. Engineering schematic of the Geumdang Bridge including the location of the instrumented accelerometers

tinuous span that is supported along its length by three piers (the piers are denoted as Piers 4, 5 and 6 in Fig. 2) and the southernmost concrete bridge abutment. At each support (pier and abutment), the span sits on elastomeric pads that serve as simple supports. The Geumdang Bridge has been selected for instrumentation in this study because the bridge has been instrumented in the past and its modal properties are published (Lee *et al.* 2004).

4 INSTRUMENTATION STRATEGY

Two independent structural monitoring systems are installed in the bridge to monitor its response during forced vibration testing. The first monitoring system is a traditional tethered system using cables to communicate sensor readings to a centralized data server. The second system is a wireless structural monitoring system assembled from the low-cost wireless sensing unit prototypes described in previous sections. Installation of two separate monitoring systems allows the wireless monitoring system performance to be directly compared to that of the tethered system. Both the wireless and tethered structural monitoring systems employ accelerometers to measure the vertical response of the bridge span.

Accelerometers are installed within the interior spaces of the Geumdang Bridge's concrete box girder. In particular, two different types of accelerometer are installed. The PCB Piezotronics 393B12 piezoelectric accelerometers are the first set installed with the tethered monitoring system. The PCB Piezotronics 393B12 accelerometer is a high-sensitivity sensor designed for seismic applications including structural monitoring. The performance specifications of the accelerometer are documented in Table 1. The second accelerometer family selected for the wireless structural monitoring system is the PCB Piezotronics 3801D1FB3G accelerometer. The performance specifications of this low-cost capacitive MEMS accelerometer are also presented in Table 1.

In total, 14 accelerometers are supplied from each accelerometer family for installation along the length of the concrete box girder. The accelerometers are installed in the locations denoted as #1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15 and 16 in Fig. 1. At each sensor location, two accelerometers (PCB Piezotronics 393 and PCB Piezotronics 3801) are affixed to a mounting plate that ensures the accelerometers are perfectly oriented in the vertical direction. The portion of the box girder span that lies between Pier 5 and 6 is the most heavily instrumented. The distribution of the accelerometers is in-

Table 1. Specification of accelerometers used to measure the vertical acceleration of the Geumdang Bridge

Characteristic	PCB 393	PCB 3801
Type	Piezoelectric	Capacitive
Sensitivity	10 V/g	0.7 V/g
Range	± 0.5 g	± 3 g
Bandwidth	2000 Hz	80 Hz
Noise Floor	50 μg	0.5 mg
Dynamic Range	111 dB	95 dB
Excitation Voltage	18 V_{DC} min.	5 V_{DC} min.
Housing	Steel	Polymer

tended to provide ample data for determination of bridge modal frequencies and corresponding mode shapes. During the later phases of testing, the accelerometers attached to the wireless monitoring system are moved to alternative locations (such as locations #17 through 26); a convenience afforded by the absence of cables in the wireless monitoring system.

The tethered monitoring system consists of the 14 PCB 393 accelerometers attached to a centralized data acquisition computer through coaxial wires that run along the center of the box girder's interior area. The accelerometers' coaxial cables are interfaced to the 16-channel PCB Piezotronics 481A03 signal conditioning unit. To provide improved accuracy in reading the voltage output of the PCB 393 accelerometers, the tethered monitoring system is configured to amplify the accelerometer voltage signal by a factor 10 during forced vibration testing. The signal conditioning unit is interfaced to a laptop through the National Instruments' 12-bit data acquisition card (model number 6062E). All of the acceleration response channels are sampled at 200 Hz.

To record the bridge response measured by the PCB 3801 accelerometers, one wireless sensing unit prototype is deployed in tandem with each accelerometer. In total, 14 wireless sensing unit prototypes are installed in the bridge interior in the matter of one hour. A laptop computer, with a compatible wireless radio attached, is used to collect bridge response data from the wireless sensing units. The laptop is placed in the vicinity of accelerometer location #7 with a maximum distance between the laptop and the most extreme wireless sensing unit approximately 65 m. The laptop computer can control the entire network of wireless sensing units and serves as a centralized repository for the storage of acceleration measurement data. The units collect data at the prescribed sampling rate while simultaneously communicating data to the laptop. There is a limited amount of bandwidth available to the wireless radio attached to the laptop computer. To prevent this single receiver from exceeding its bandwidth capacity, the sampling rates of the 14 wireless sensing units are set to 70 Hz. Faster sample rates would cause data to be generated too fast which in turn causes the bandwidth capacity of the laptop radio to be exceeded (resulting in data loss). During some of the loading tests, the sampling rates of the wireless sensing units are increased to 200 Hz to allow for a one to one comparison to the response time-history data recorded by the tethered monitoring system. During tests with the wireless monitoring system collecting data at 200 Hz, only 4 wireless sensing units are configured to transmit their data (specifically, the wireless sensing units located at locations #6, 8, 23 and 24).

Figure 3. Three trucks (15, 30, and 40 tons) are used to induce vibrations in the Geumdang Bridge

5 FORCED VIBRATION TESTING

To validate the performance of the wireless monitoring system, the Geumdang Bridge is intentionally loaded in a well controlled manner using truck traffic. During testing, the bridge is closed to highway traffic allowing the research team to have full control over the loadings applied. To excite the bridge in the vertical direction, three large trucks of varying weight are employed: 15, 30 and 40 tons. Each truck transfers its load through 4 axes with the front axis taking 21% of the total truck load, the second axis taking 27%, and the remaining two back axis each taking 26%. The three trucks utilized during testing are also shown in Fig. 3.

During testing, only one truck is driven over the Geumdang Bridge at a time. When the trucks are driven across the bridge, they are driven at a controlled velocity; only three velocities, 40 km/hr, 60 km/hr and 80 km/hr, are employed. For each truck speed, the three trucks are each driven in a southern direction in the right-most lane with only one truck crossing the bridge at a time. After all three trucks have crossed the bridge, they are driven at a low speed (< 10 km/hr) back to the bridge's northern side and the test repeated. For each truck speed, the three trucks are driven over the bridge in a southern direction 4 times. Table 2 summarizes the sequence of testing performed during forced vibration testing of the Geumdang Bridge.

During forced vibration testing of the Geumdang Bridge, three testing goals are established. The first testing goal is to compare the time-history acceleration response of the wireless monitoring system to that of the baseline tethered monitoring system. The second goal is to validate the accuracy of beacon time synchronization method embedded in the wireless sensing units. The last testing goal is to illustrate the embedded computing capabilities of the wireless sensing units by having the units calculate and communicate the Fourier frequency spectrum corresponding to the bridge acceleration response.

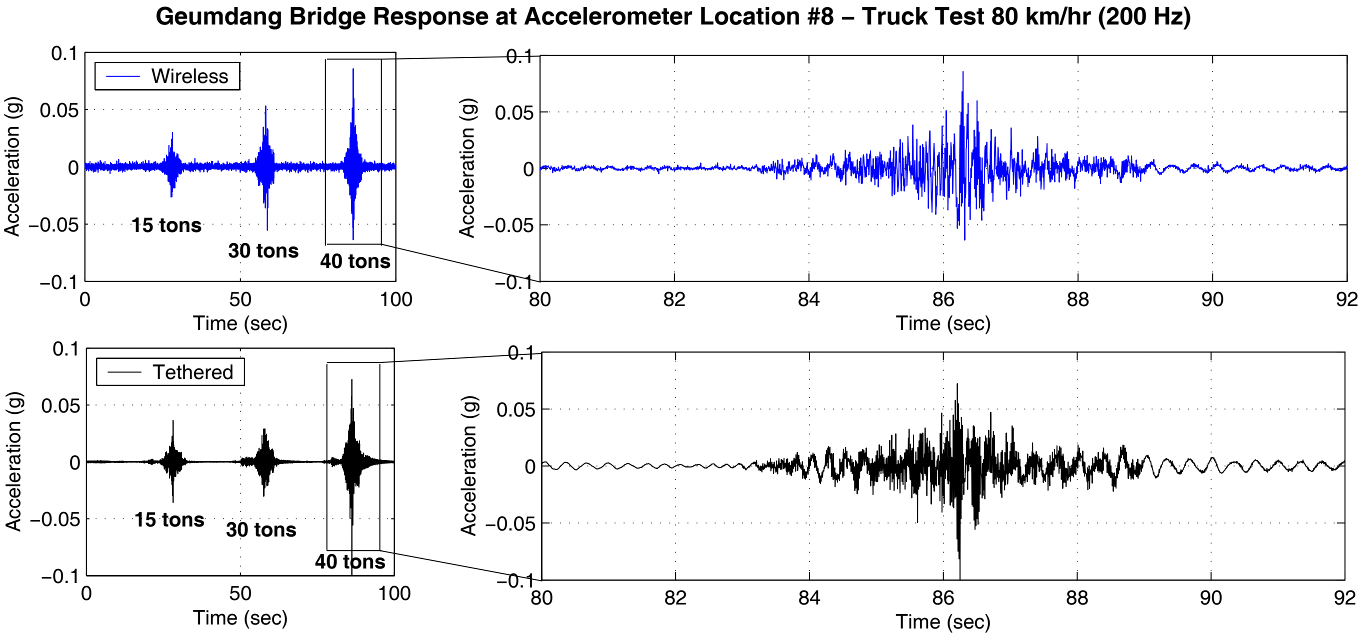


Figure 4. Acceleration response of the Geumdang Bridge at sensor location #8 while three trucks (15, 30 and 40 tons) transverse sequentially at 80 km/hr. The wireless (top) and tethered (bottom) monitoring systems both collect data at 200 Hz.

5.1 *Geumdang Bridge Acceleration Response*

For each loading scenario, the wireless monitoring system proves to be capable of collecting data with high measurement fidelity when compared to the tethered monitoring system. For example, if the bridge acceleration response data collected by both monitoring systems are compared, there exists a strong one-to-one correspondence. As shown in Fig. 4, the response of the bridge at sensor location #8 is plotted for both the wireless and tethered systems when the three trucks (15, 30 and 40 tons) are driven over the bridge at 80 km/hr. To facilitate a fair comparison with the tethered monitoring system, the wireless sensing unit at sensor location #8 is configured to sample the accelerometer output at 200 Hz for this one test. The wireless sensing unit is sufficiently accurate to fully capture the bridge response during the period when the trucks transverse the bridge span. As is witnessed for the 40 ton truck, the wireless monitoring system is also able to capture the free vibration response of the span even after the trucks have exited the bridge.

Table 2. Loading sequence of the Geumdang Bridge

Test Set	Truck	Speed
Set 1	15 → 30 → 40 tons	40 km/hr
	15 → 30 → 40 tons	40 km/hr
	15 → 30 → 40 tons	40 km/hr
	15 → 30 → 40 tons	40 km/hr
Set 2	15 → 30 → 40 tons	60 km/hr
	15 → 30 → 40 tons	60 km/hr
	15 → 30 → 40 tons	60 km/hr
	15 → 30 → 40 tons	60 km/hr
Set 3	15 → 30 → 40 tons	80 km/hr
	15 → 30 → 40 tons	80 km/hr
	15 → 30 → 40 tons	80 km/hr
	15 → 30 → 40 tons	80 km/hr

The PCB Piezotronics 3801 accelerometer instrumented at sensor location #8 has an RMS noise floor of approximately 0.5 mg. This result is consistent with both with the accelerometer's data sheet as well as with the other PCB 3801 accelerometers which all had noise floors of in the vicinity of 0.5 mg. However, four of the accelerometers installed on the bridge exhibit noise floors greater than the documented noise floors. In particular, the accelerometers located at sensor locations #1, 6, 14 and 15 had noise floors of approximately 2.5 mg. The elevated noise floors are suspected to be either the result of the accelerometers incurring some damaged during transportation to the bridge site or the result of a faulty connector employed between the accelerometers and the wireless sensing units. Even with elevated noise floors, the bridge's acceleration response measured at these four locations (#1, 6, 14 and 15) is still accurately measured.

To illustrate the quality of the response data collected by the wireless monitoring system, the time-history response is transformed to the frequency domain by conducting Fourier analysis with the data. Fourier frequency spectrums of the bridge are calculated offline after the completion of the test. The intention of calculating the spectrums is to identify the modal frequencies of the Geumdang Bridge.

Prior to transforming the time-history response of the bridge to the frequency domain, the response data is divided into shorter time segments corresponding to the different truck weights and speeds. The Fourier frequency spectrum calculated using the bridge response data at sensor locations #7, 9 and 13 generated by the 15 ton truck traveling at 40 km/hr are presented in Fig. 5. The Fourier frequency spec-

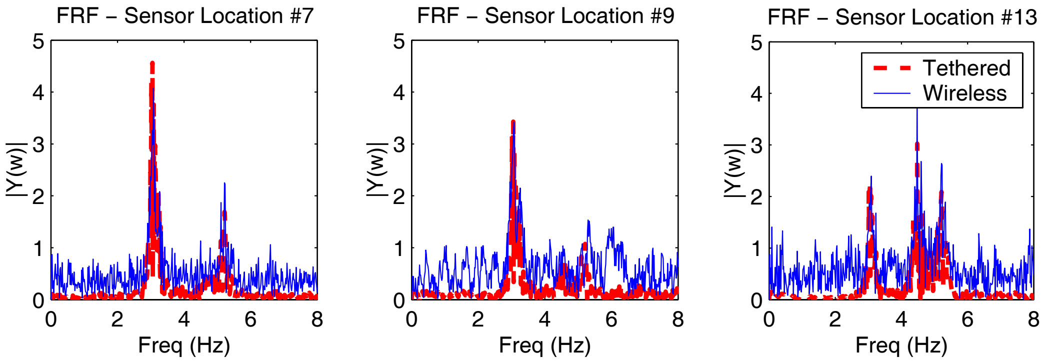


Figure 5. Fourier frequency spectrum calculated from the Geumdang Bridge acceleration response measured at sensor locations #7, 9 and 13 by both the wireless (70 Hz) and tethered (200 Hz) monitoring systems.

trums are calculated from both the wireless monitoring system data (whose sample rate is 70 Hz) and that of the tethered monitoring system (whose sample rate is 200 Hz). The frequency spectrum magnitudes are scaled to account for the different sampling rates. As can be clearly seen in Fig. 5, the frequency spectrums that correspond to the two different monitoring systems are in strong agreement. The first three modal frequencies are identifiable: 3.1, 4.5 and 5.2 Hz. These primary modal frequencies are nearly identical to those identified during previous field testing of the bridge: 3.1, 4.5 and 5.0 Hz (Lee *et al.* 2004).

With no data corresponding to the input excitation available, accurate calculation of the Geumdang Bridge mode shapes are not possible. Rather, the operational deflection shapes of the bridge can be estimated from the frequency spectrums calculated using both monitoring systems' response data. The operating vectors are determined by selecting the imaginary component of the Fourier frequency spectrum at each modal frequency. If a structure's modal frequencies are spaced far apart, the structure has low damping and the excitation inputs are assumed to have a constant spectrum across all frequencies of interest, then the operating vectors are approximately equal to the mode shapes (Peeters and Ventura 2003). In many of the output-only bridge instrumentation studies reported in the literature, the input spectrum is assumed constant to facilitate identification of bridge mode shapes (Brownjohn *et al.* 2003).

For the bridge response corresponding to the 15 ton truck traveling at 40 km/hr, the operational deflection shapes are determined using the frequency spectrums calculated at each sensor location. Fig. 6 presents the three operational deflection shapes that correspond to the first three modal frequencies at 3.1, 4.5 and 5.2 Hz. The three operational deflection shapes calculated from the wireless and tethered monitoring systems are superimposed upon the same plot. Based on visual inspection of the three operational deflection shapes, the shapes determined from the wireless monitoring system are closely correlated with those determined from the tethered monitoring system response data. The shape magnitude at sensor locations #1 and 14 for the first and third operational deflection shapes are noticeably different from the magnitudes determined using the tethered system response data. The inaccuracy of the shapes at these two sensor locations is attributed to the unusually high noise floor associated with the MEMS

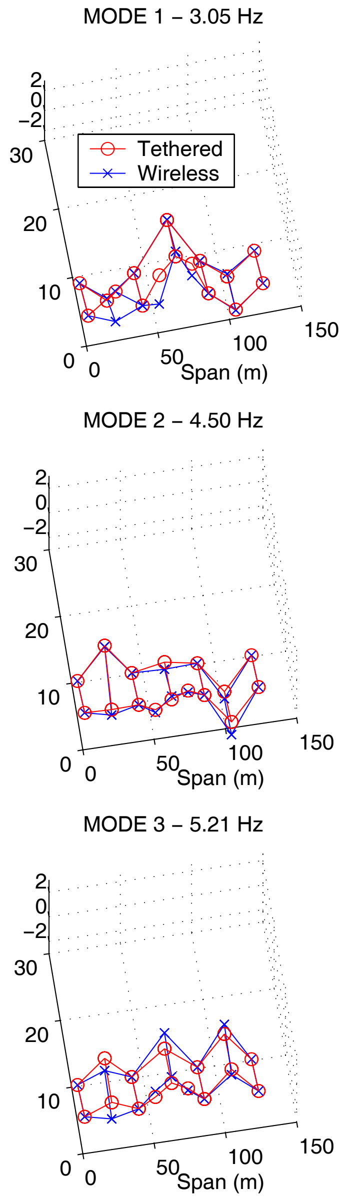


Figure 6. Operational deflection shapes corresponding to the first three modes of the Geumdang Bridge. Shapes correspond to the 15 ton truck crossing the bridge at 40 km/hr.

accelerometers. However, the operational deflection shape corresponding to the second mode is accurately calculated using the wireless monitoring system data.

5.2 *Wireless Monitoring System Time Synchronization*

An important limitation of wireless monitoring systems is the absence of a centralized clock. Unlike tethered monitoring systems where the data repository has a single clock for time stamping all measurement data, the decentralized nodes of the wireless monitoring system must keep their own time. Particularly for wireless sensor networks where nodes are distributed over large spatial areas, clock synchronization is a difficult task.

The wireless sensing unit prototype used in this study is designed to synchronize its internal clock to a beacon signal broadcast from the centralized data repository. This clock synchronization approach is identical to that used in commercial wireless radios such as 802.11 and 802.15.4 transceivers (Callaway 2003). After all of the wireless sensing units have synchronized their internal clocks to the same beacon signal, their measured response time-histories transmitted to the data repository are synchronized. However, an inherent limitation of this approach is the presence of stochastic delays in the wireless channel; if a wireless sensing unit is delayed in synchronizing to a common beacon signal, its clock will lag the remainder of the wireless sensing unit network. The precision of the beacon-based time synchronization will reduce as wireless sensing units are spaced further apart as a result of wireless channel delays increasing proportionally with range.

The Geumdang Bridge offers a unique opportunity to measure the accuracy of the wireless sensing unit's time synchronization algorithm within a realistic structural environment. The wireless sensing units acceleration response data, $\bar{a}_i(k)$, at a given sensor location, i, will be compared to the corresponding bridge response synchronously recorded by the tethered monitoring system, $a_i(k)$. To measure if any errors occur in the time synchronization of the wireless sensing units, the difference, $e_i(k)$, between the bridge response measured by each wireless sensing unit and the tethered monitoring system is calculated. The vector norm of the error time-history, $|e_i(k)|$, represents a scalar measure of the synchronization error in the wireless sensing unit response data. If a wireless sensing unit is perfectly synchronized to the corresponding tethered monitoring system channel, then the error vector norm would be minimized. The wireless response data is shifted relative to the tethered monitoring system channel until the minimal vector norm of the error time-history is found. This shift is then an accurate measure of the wireless sensing unit's synchronization error.

Table 3. Time synchronization error of the wireless sensing units instrumented within the Geumdang Bridge

Sensor Location	Step Delay	Time Delay	Sensor Location	Step Delay	Time Delay
1	1	0.014s	9	8	0.115s
-	-	-	10	1	0.014s
3	1	0.014s	11	0	0 s
4	1	0.014s	-	-	-
5	0	0 s	13	0	0 s
6	0	0 s	14	6	0.086s
7	0	0 s	15	0	0 s
8	0	0 s	16	0	0 s

Using the acceleration response of the bridge during the 15 ton truck traveling at 40 km/hr, the wireless sensing units measurement data is compared to that taken by the tethered monitoring system. Because the tethered monitoring system samples data at 200 Hz, a linear re-sampling algorithm is employed to down sample the tethered response data to 70 Hz. The wireless monitoring system is found to have little to no error in synchronization. Table 3 summarizes the amount of delay present in the wireless sensing units compared to the tethered monitoring system. As can be seen by values in Table 3, only two of the wireless sensing units, located at sensor location #9 and 14 experience significant delays of approximately 0.1 s. Otherwise, the wireless sensing units are shown to by fully synchronized or synchronized within one time step (0.0143 s).

5.3 *Embedded Fourier Spectrum Calculation*

The wireless sensing unit is designed with sufficient on-board computational resources to allow the unit to locally interrogate measurement data. During field testing of the Geumdang Bridge, the wireless sensing units are configured to record the acceleration response of the bridge, and to calculate the corresponding Fourier frequency spectrums. To calculate the frequency spectrums from acceleration response data, the Cooley-Tukey implementation of the fast Fourier transform (FFT) is embedded in the core of the wireless sensing unit (Press *et al.* 1992). A similar implementation of the Cooley-Tukey FFT algorithm within the computational core of a different wireless sensing unit prototype has been reported by Lynch *et al.* (2003b).

Fig. 7 presents the Fourier spectrum of the Geumdang Bridge response corresponding to sensor location #15. The wireless sensing unit performs a 4096 point FFT analysis on the bridge acceleration response data collected when the 30 ton truck is traveling at 60 km/hr. After the frequency spectrum is calculated by the wireless sensing unit, the first 2048 points of complex valued function below the Nyquist frequency are wirelessly transmitted to the data

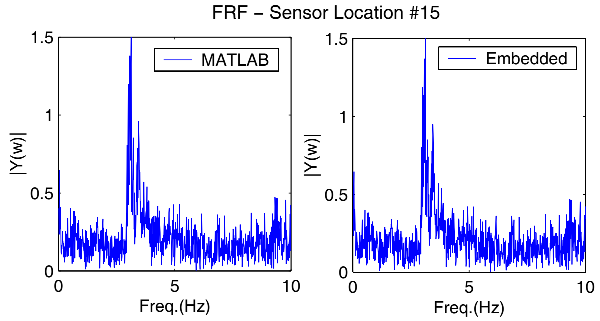


Figure 7. Frequency response function calculated by the wireless sensing unit and offline using MATLAB. Response corresponds to sensor location #15.

repository along with the raw time-history response data. To compare the accuracy of the embedded FFT analysis, the 4096 point frequency spectrum is calculated offline in MATLAB using the raw acceleration time-history data. As can be seen in Fig. 7, the embedded FFT and MATLAB FFT yield the exact same results.

6 CONCLUSIONS

This study has focused upon the deployment of a large-scale wireless structural monitoring system within the long-span Geumdang Bridge. In total, 14 wireless sensing units were installed throughout the span's concrete box girder. A tethered structural monitoring system has been installed in parallel with the wireless monitoring system so that the measurement quality and time synchronization error of the wireless monitoring system could be assessed in a realistic field setting. The results obtained from the wireless sensing units were impressive. Acceleration time-history response records were accurately measured using MEMS accelerometers. Furthermore, accurate clock synchronization across the network of wireless sensing units was possible, often within one sample increment. The computational resources available on the wireless sensing unit were also illustrated during testing by commanding the wireless sensing units to calculate Fourier frequency spectrum using bridge response data.

This field study represents the first phase of a multi-phase collaboration between researchers at the University of Michigan, Stanford University and KAIST. During field testing, some limitations of the wireless sensing units were identified including higher than expected noise floors. Current research is focused upon improvement of the wireless sensing unit hardware in preparation for future installation in the Geumdang Bridge.

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