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Smart Sensing Techniques for Health Monitoring of Existing Bridge

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ABSTRACT:

In India, the most common health monitoring systems for different structures are by manual is in practice. But in a competitive world, there is a need of real time monitoring as a part of Internet of Things. To study the performance of the developed wireless sensor platforms in real field problems, experimental studies were carried out on the health assessment of a prestressed concrete girder bridge by deploying the developed wireless sensor systems. Conventional sensor system was deployed for comparing the performance of the wireless sensor system. Hence the wireless sensor system shall be used for structural health monitoring applications.

Keywords: Structural Health Monitoring (SHM), bridges, wireless sensor networks.

I. INTRODUCTION:

Various SHM strategies have been proposed in the previous couple of decades. But there are few challenges in applying them to civil infrastructures. Most existing SHM strategies essentially requires the measurement of the magnitude of loads coming on the structure to assess its performance. However, in many cases, it is difficult to measure the loads coming on the structure (bridges) or alternatively, it is more difficult to create such loading in the structures for getting the responses. This difficulty has limited the utilization of existing SHM strategies for assessing the health of civil engineering structures, which require the measurement of loads. Techniques utilising ambient vibrations in the structure due to loadings have become more prominent for structural health monitoring and health assessment. But still more research endeavours are required towards the development of health assessment techniques that will use the ambient vibration of structures. Another difficulty in applying the existing SHM strategy is the occurrence of damage is a local phenomenon. Sensors present near to the damage location records maximumresponses when compared with those present away from the damage. Therefore,to effectively detect the location of damage in a structure, sensors must be closely distributed throughout the structure. Using a conventional wired sensor system, it will be quiet difficult to assess the health of a structure by deploying many number of sensors because of the challenges in routing the cables from the sensor locations to the central data acquisition system. Structural health monitoring system employing wired sensors is shown in Figure 1. The cabling required for connecting the sensors instrumented for monitoring large civil engineering structures to the central data acquisition system is more complicated and difficult to manage since the cables are prone to get damaged easily.

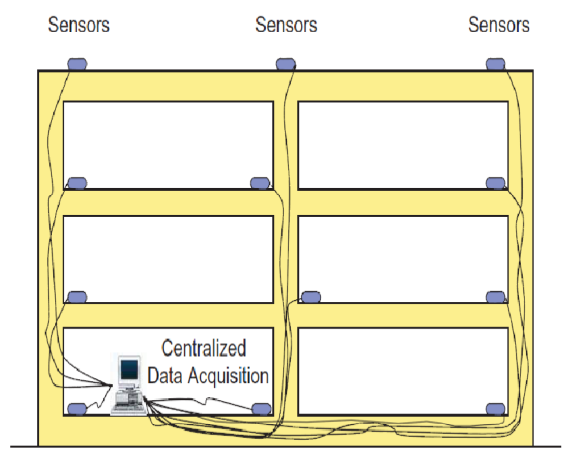

Figure 1. Schematic representation of wired structural health monitoring

Recent advancements in smart wireless sensors has made SHM to use many number of sensors. The basic component of a wireless smart sensor is the microprocessor which performs the node level computations and make the sensor to be smart. Programs can be developed and uploaded to the sensor’s microprocessor, by which the smart sensors can record data locally at the nodelevel, perform few computations at the node level, make decisions, extract onlyvaluable information, send results to the control system, etc. Hence, a few computations can be done at the node level itself for detecting damage. Unwanted information like signal noise can be eliminated at the node level thereby reducing the volume of information that needs to be sent to the central station which is not possible in the conventional sensor system. The smart wireless sensors have the wireless communication capabilities for wireless data transfer. A schematic representation of the wireless structural health monitoring system is shown in Figure 2.

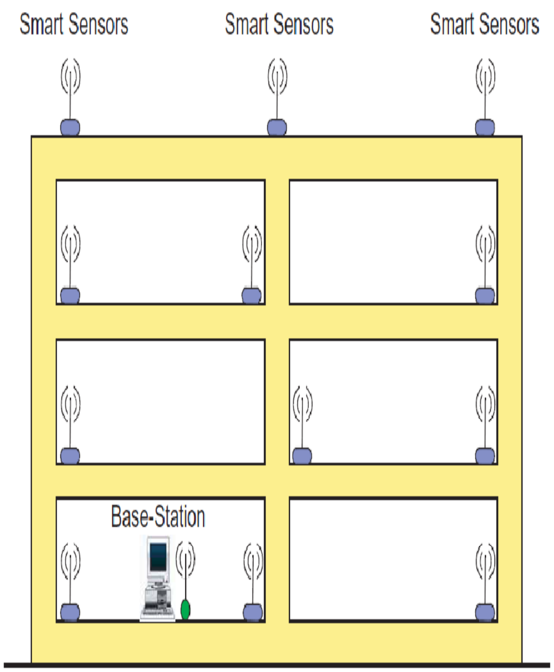

Figure 2. Schematic representation of wireless structural health Monitoring

Smart wireless sensor technology provides distributed computing environment that can be utilised by the damage detection algorithms for the development of effective SHM strategies. Hence by deploying many number of low-cost smart wireless sensors and using their computational and communication capabilities, the quality of SHM can be improved. These smart wireless sensors provide essential information that can be utilized to detect, locate, and assess structural damage caused by severe loading and environmental deterioration. Information from these smart wireless sensors gives a better understanding on the physical state of the structural system.

II. WIRELESS SENSOR NETWORKS:

A wireless sensor network consists of a sensor, computational hardware and communication hardware. A wireless sensor system can be deployed in a structure for monitoring purposes. The four basic components in a sensor networks are:

(1) An array of different kinds of sensors

(2) A wireless node for communication between sensors and base staion

(3) A local base station for collecting data from the wireless nodes

(4) Control station to handle data from different base stations for post processing.

The best advantage of WSN in structural health monitoring is that, the sensing and computation can be done at the sensor node itself. Since large quantity of data is collected in SHM, data compression and synthesis algorithms are essential for data management. WSN is a trans-disciplinary research area that involves communication and networking, analysis of the signals, management of data, system architectures for user-friendly administration, power management algorithms, and platform technology (hardware and software, such as operating systems).

III. WSN IN STRUCTURAL HEALTH MONITORING

Structural health assessment techniques can be broadly classified into local and global techniques. Local techniques aims at finding highlylocalized damages in a structure. These techniques include ultrasonic, thermal,X-ray, magnetic or optical imaging techniques, but this type of inspection requires a significant amount of time, skilled manpower and disruption of thenormal operation of the structure. In global inspection techniques the health ofthe structure is evaluated by analysing its response to an external excitation. Theexcitation can be ambient (wind loads, vehicle movements in bridges) or forced. In either case, modal parameters, such as naturalfrequencies, damping ratios, and mode shapes are evaluated to identify damagein the form of expansion, de-lamination, corrosion, etc.

In recent years researchers have been developing and testing wireless sensor networks as part of structural health monitoring applications, where distributed sensors record the vibration responses in the structures. Accordingly, potential damage can be localized and its extent can be estimated in real time. WSN is being developed to address the limitations of existing SHM techniques which rely on either periodic visual inspections or expensive wired data acquisition systems.

IV. PERFORMANCE EVALUATION OF A PRESTRESSED CONCRETE GIRDER BRIDGE USING WIRELESS SENSOR SYSTEM

Performance evaluation of a prestressed concrete girder bridge was carried out by deploying the developed wireless sensor system at the bridge site. To study the performance of the wireless sensor system conventional sensors were also used at the bridge site. The details of the experimentalinvestigations are explained in the following sections.

Table 1

SI.NO	Features	Details
1	Superstructure type	Prestressed concrete girder
2	Effective span	12.9m
3	Depth of girder	1.676m
4	Slab thickness	147mm

A.Instrumentation and Deployment of the Wireless Sensor system

Performance evaluation of the bridge involves measuring the parameters like strain and acceleration on the bridge. Strain responses were obtained from the strain gages that were instrumented on the bridge girder and connected to the Ni wireless sensor nodes. Acceleration responses from the bridge girder was obtained by instrumenting the Waspmote wireless sensor nodes. These measured responses were used to evaluate the structural properties of the bridge girder like bending moments, shear forces and frequencies. The Waspmote wireless sensor to be deployed at the site for instrumentation. Since the bridge is simply supported on the bridge piers, the maximum strain will develop at the midspan. Hence the midspan section was instrumented with strain gages at top and bottom of the girder for obtaining the bending moments and also with an accelerometer for measuring the accelerations. Additionally, to get the variation of the bending moment along the span, one-fourth sections were also instrumented with the strain gages at top and bottom. To get a better understanding of the vibration in the bridge, Waspmote wireless sensors were rigidly fixed to the girder at every one fourth locations. Strain gages were instrumented on the girder at the two support ends to obtain the variation of the shear force in the girder. The girder was also additionally instrumented with the conventional sensor system at the locations instrumented with the wireless sensor system for comparing the performance of the wireless sensor system.

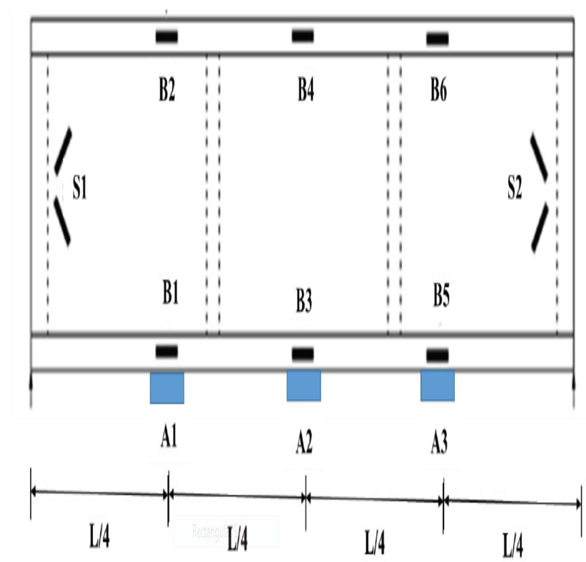

Figure 3. Typical instrumentation scheme for the bridge girder

B1 to B6 are the locations instrumented with strain gages for measuring the bending moments and S1, S2 are the locations instrumented with strain gages for measuring the shear forces. A1 to A3 are locations instrumented with accelerometers for measuring the vibrations in the bridge during. Adjacent to these locations additional strain gages and accelerometers were instrumented for measurement using conventional data acquisition system. These measurements were used for comparing the performance of the deployed wireless sensor system. The strain gages were connected to the NI wireless nodes in full bridge configuration. The wireless nodes were powered on and communication between the nodes and gateway was established successfully. The Waspmote wireless sensor nodes were also powered on and communications were successfully established between the wireless nodes and base station. The wireless nodes were powered using the battery board and rechargeable batteries. The additional conventional strain gages and accelerometers were connected to a conventional data acquisition system.

B.Evaluation of Calibration Constants

The bridges are subjected to dynamic loads. It is very difficult to evaluate the bending moments and shear forces due to these varying loads. Hence static tests were carried out on the bridge using a test formation and calibration factors were evaluated to convert the dynamic strains measured into dynamic bending moments and shear forces.

Three static tests were conducted by positioning the loco and heavily loaded wagons at predetermined locations on the span. Calibration factors were obtained by correlating the maximum values of static strain measured at various sections with the corresponding theoretical bending moment. In static test-1, the six axles of the loco were placed symmetrically about the centre of the instrumented bridge span. Static test-2 refers to the position of loco for maximum bending moment. The axles of loco were placed in such a way that maximum bending moment occurs over the span. Static test-3 refers to the position of wagons placed centrally on the span. Similar to the first static test case, the wagons were positioned centrally over the instrumented span. The schematic representation of the axle positions and the wheel loads for static load cases. The strains measured from the conventional sensor system was compared with that of the strain measured from the wireless sensor system and given in Table 2. From the Table it can be seen that the variation between the conventional system and the wireless system is less than7%. It can be inferred that the strain responses measured in the girder is transmitted to the base station without any signal noise, signal transmission losses and electro-magnetic interference from the over-head electric cables. Hence the wireless sensor system can be effectively used for the field applications like performance evaluation of bridges. Numerical studies were carried out to evaluate the theoretical bending moment and shear force in the girder for the static load test cases. The theoretical bending moment and shear force was correlated with the strain response measured from the wireless sensor for evaluating the calibration factors as shown in Table 3 and Table 4.

Table 2. Comparison of strain responses measured from wireless sensor system and conventional dataacquisition system

Static load case	**Location**	**Measured strain in microstrain**		**Variation in %**
		Conventional	**Wireless**	
1	B1-B2	37	38	2.7
	B3-B4	60	62	3.3
	B5-B6	43	41	4.6
	S1	14	14	0.0
	S2	15	16	6.6
2	B1-B2	37	39	5.4
	B3-B4	39	38	2.5
	B5-B6	22	23	4.5
	S1	21	22	4.7
	S2	7	7	0.0
3	B1-B2	41	42	2.4
	B3-B4	54	51	5.5
	B5-B6	40	42	5.0
	S1	19	20	5.2
	S2	22	21	4.5

Table 3. Evaluation of calibration constants from static tests for bending moment

Static load case	**Location**	**Theoretical Bending Moment in kNm**	**Bending Strain in Micro Strain**	**Calibration Factor**	**Experimental Bending Moment (WSN) in kNm**
1	B1-B2	495.80	38	13.047	488.30
	B3-B4	796.96	62	12.854	796.70
	B5-B6	495.80	40	12.395	514.00
2	B1-B2	528.42	40	13.210	514.00
	B3-B4	488.80	38	12.863	488.30
	B5-B6	285.87	23	12.429	295.55
3	B1-B2	558.60	42	13.300	539.70
	B3-B4	657.36	51	12.889	655.35
	B5-B6	558.60	43	12.990	552.55
Average Calibration Factor				12.850	

Table 4. Evaluation of calibration constants from static tests for shear force

Static Load Case	1		2		3	
Location	S1	S2	S1	S2	S1	S2
Theoretical shear force in kN	153.71	153.71	238.32	69.10	206.27	206.27
Shear strain in microstrain	15	16	23	7	20	21
Calibration factor	10.20	9.61	10.40	9.87	10.30	9.82
Average calibration factor						10.03
Experimental shear force(WSN) in kN	150.45	160.48	230.69	70.21	200.60	210.63

From the static tests, the average calibration factor evaluated as 12.85 will be used for converting the bending strains measured during dynamic tests to bending moments. From the static tests, the average calibration factor evaluated as 10.03 will be used for converting the shear strains measured during dynamic tests to shear forces. From the static tests, the maximum shear and moment due to live loads are found to be 230.69 kN and 796.70 kNm respectively.

Table 5. Acceleration of the bridge

Dynamic load case	Maximum values of Acceleration in m\s^2		
	A1	A2	A3
1	4.33 (4.38)	4.55 (4.37)	4.41 (4.15)
2	4.46 (4.14)	4.50 (4.66)	4.19 (4.11)
3	4.91 (4.26)	4.71 (4.96)	4.63 (4.05)
4	3.67 (3.08)	3.04 (3.51)	3.19 (3.02)
5	3.08 (2.97)	3.14 (2.89)	3.57 (3.19)

Note: Values in brackets corresponds to conventional sensor

Table 6 . Frequency of the bridge

Dynamic load case	Frequencies in Hz		
	I	II	III
1	5.40 (5.39)	10.90 (10.00)	29.79 (30.01)
2	5.48 (5.71)	8.34 (10.01)	31.60 (31.84)
3	5.60 (5.31)	11.22 (10.16)	31.91 (30.08)
4	4.91 (4.83)	10.47 (11.05)	29.68 (31.77)
5	4.81 (4.18)	10.05 (11.30)	28.87 (29.11)

Note: Values in brackets corresponds to conventional sensor

V. CONCLUSION

Experimental studies were carried out on the health assessment of a prestressed concrete girder bridge by deploying the developed wireless sensor systems. These studies were carried out to evaluate the efficiency of the developed wireless sensor system under real field applications. Conventional sensor system was also deployed for comparing the performance of the wireless sensor system. From the studies carried out on the performance evaluation of prestressed concrete girder bridge, the shear force and bending moment responses were varying less than 2% with that of the conventional sensor system. The acceleration and frequency responses had variations less than 9%. From the experimental investigations it was found that the responses from the wireless sensor system was in good agreement with that of the conventional sensor system. Hence the wireless sensor system shall be used for structural health monitoring applications.

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