Trigger Analysis for Wireless Bridge Earthquake Monitoring System

George V. MINESAWA
Assistant Professor
Tokyo Institute of Technology, Tokyo, Japan
minesawa.g.aa@m.titech.ac.jp

George Vulpe Minesawa, born 1969, received civil eng. degree from Tech. Univ. Gh. Asachi, Iasi and is with Tokyo Institute of Technology since 2011.

Eiichi SASAKI
Associate Professor
Tokyo Institute of Technology, Tokyo, Japan
sasaki.e.ab@m.titech.ac.jp

Eiichi Sasaki, received Degree of Doctor of Engineering from Tokyo Institute of Technology.

Hisada SUGANUMA
Associate Professor
Tokyo Institute of Technology, Tokyo, Japan
suganuma.h.aa@m.titech.ac.jp

Hisada Suganuma, received his civil engineering degree from the Tokyo Institute of Technology.

Summary

Bridge Structural Health Monitoring (SHM) system could provide the assessment of the bridge structure condition immediately after the occurrence of a major seismic event, potentially enhancing safety and reducing the time needed for evaluating the bridge state before bridge is being returned to service. The bridge wireless SHM sensor node operates on batteries and records data intermittently, when triggered. The sensors located on the bridge records both seismic events and various traffic induced vibrations. An independent triggering algorithm of each sensor node using the acceleration data recorded on the bridge piers has been adopted. Several trigger algorithms are being compared for enhancing detection of seismic events in the presence of the traffic and wind induced vibration. The preliminary analysis of the data at the bridge setup location is being used for the validation of the proposed triggering algorithm.

Keywords: Earthquake trigger; SHM; bridge monitoring; sensor node trigger.

1. Triggered wireless SHM system

The proposed wireless SHM sensor node operates on batteries and records data intermittently, when triggered or on schedule as set from the base station. As the continuous data recording is expensive in term of storage and memory, and the transmission of a large volume of data over wireless network is time consuming and reduces battery life, triggered data recording has been implemented, with the sensor node being triggered by the external monitored signal, such as the accelerations. The detection of earthquake triggers for bridge mounted sensors is complicated by the high level of vibrations induced by traffic and wind. Wireless sensor monitoring is triggered by a threshold trigger level to reduce trigger latency and recorded data are stored into memory. The trigger level is determined from distribution of the sorted RMS values of bridge accelerations on the bridge as plotted in Fig. 1. Due to bridge's characteristics, large accelerations are recorded on the vertical and transversal directions during strong winds induced by a typhoon. To prevent continuous triggering of the wireless sensors the allowable trigger threshold is determined herein above the typical vibration level, so that one trigger is detected at a certain wind induced acc. threshold. Further on, an in-memory event classification algorithm is being used to determine seismic events triggers and traffic induced triggers in bridge recorded data.

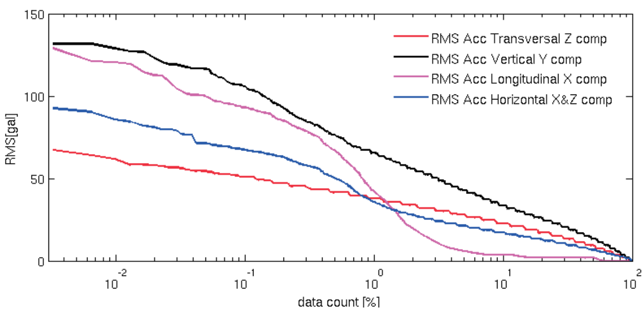

Fig. 1 Distribution of absolute values of acc. on bridge central span due to wind induced vibrations

2. EFFECTIVNESS OF TRIGGER ALGORITHM

To reduce trigger latency, a low delay triggering algorithm is proposed to be implemented in the sensor node to trigger the onset of monitoring. Such trigger algorithm is typically a threshold level trigger. Following the onset of data recording, a set of trigger algorithms where tested for the further discerning between noise and events by extracting the large events due to earthquake, strong wind and the passage of large vehicles. Noise and low intensity data recording could be identified and discarded resulting in a reduction of the volume of data being transmitted over the wireless links.

Table 1. Event detection algorithm summary

Algorithm Class	Algorithm Code ID	Algorithm Description	Algorithm Formula
Trigger level	TR-LEVEL-1D	Threshold trigger level uni-comp Transveral	abs(x(i)) > TR_LEV
	TR-LEVEL-2D-Horiz	Threshold trigger level 2D H-dir (Tr. + Long.)	sqrt(x*x(i) + z*z(i)) > TR_LEV
Trigger RMS Avrg.	TR-RMS-MEAN-1D	Thr. trigger RMS level uni-comp Transveral	MEAN(abs(x(i))) > TR_LEV
	TR-RMS-MEAN-2D-Horiz	Thr. trigger RMS level 2D H-dir (Tr. + Long.)	MEAN(sqrt(x*x(i) + z*z(i)))>TR_LEV
Trigger STA/LTA	TR-STA-LTA-1D-Transv	STA/LTA algorithm 1D H-dir (Transversal)	STA(x(i))/LTA(x(i)) > TR_LEV
	TR-STA-LTA-2D-Horiz	STA/LTA algorithm 2D H-dir (Tr. + Long.)	0.5*(STA(x(i))/LTA(x(i)) + STA(z(i))/LTA(z(i)))>TR_LEV
Trigger CWT Wavelet	TR-CWT-1SC	Thr. trigger CWT single scale level	WSc(i)> TH_LEV
	TR-CWT-nSC	Thr. trigger CWT multi scale level	MEAN (WSc(i)) > TH_LEV

3. EVENT CLASSIFICATION

Following the reception of the data into memory, the continuous wavelet transformation (CWT) trigger algorithm was used further to discrimination earthquake triggers from the traffic and wind induced vibrations. The application of the proposed CWT multi-scale trigger algorithm for detection of a seismic event is shown in Fig. 3, applied to bridge transversal direction data, discriminating presence of the earthquake event in presence of normal traffic and wind induced vibrations. Compared trigger algorithms are able to detect the events with varying performance in terms of reliability of trigger detection, early detection of trigger event, sensibility to noise and complexity in implementation.

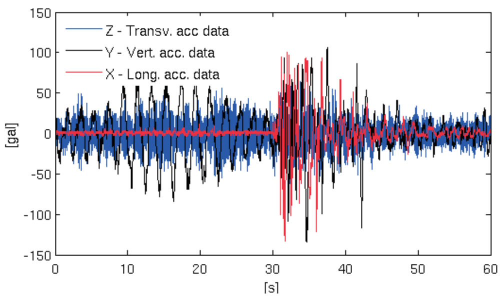

Fig. 2: Typical accelerogram on bridge central span, due to wind induced vibrations and simulated earthquake starting at to=30s

For discontinuous monitoring, threshold trigger level algorithms provide minimum time delay and are currently being implemented in the wireless sensor node. Further on, following the reception of the data into memory, CWT trigger algorithm has the ability to distinguish local occurrence of energy over a certain frequency band making it a suitable method for distinguishing events in a relatively high level background noise as typically on bridges.

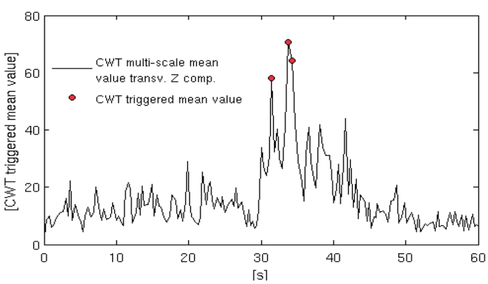

Fig. 3: Seismic event detection using CWT multi-scale trigger algorithm applied for discrimination of a simulated earthquake in transversal data component

4. CONCLUSIONS

Proposed CWT trigger algorithm allows detecting earthquake in noisy environment on the expenses of implementation complexity. Application of level trigger single station monitoring followed by in-memory event detection allows for the reduction of data transfer between sensor nodes and base station, allowing reduction of power consumption during wireless data transfer and saving storage.

Omron Social Solution Co., Ltd. and Omron Corp., Japan support is kindly acknowledged.