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SUBJECT: *EE 423/523 Graduate Course Project*

Using Matched Filter to Detect Truck Axles on the Highway Bridge

SUMMARY

The innovative Bridge Weigh-In-Motion (BWIM) system [1] uses strain sensors under the slab serving as axle detectors and strain sensors under the girder serving as weighing sensors as shown in Figure 1. However, the introduction of the matched filter from this project may have a chance to throw away the sensors under the slab and make the weighing sensors under the girder serving as the axle detector at the same time. The absence of the axles under the slab will make this system more portable and efficient.

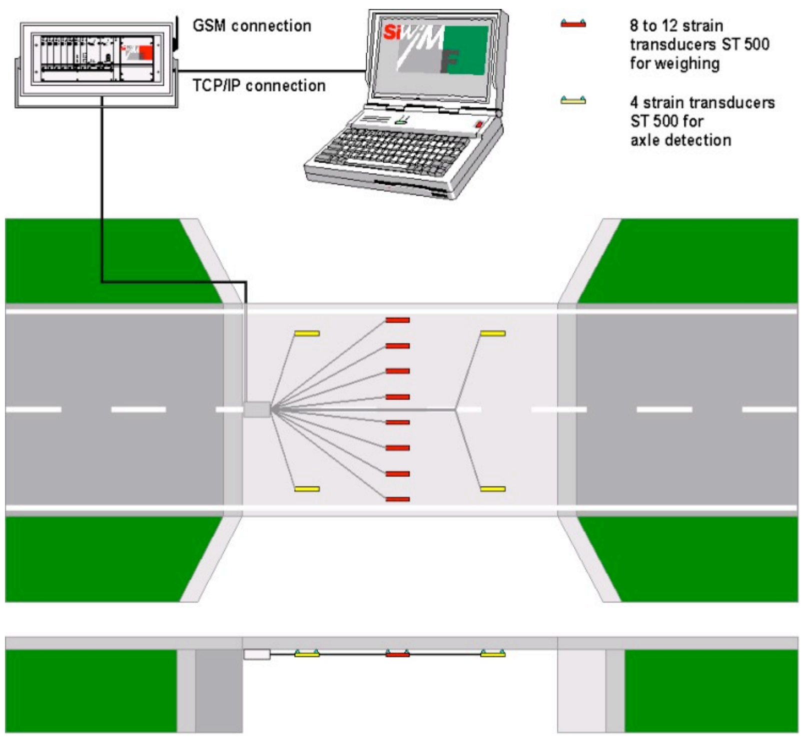

Figure 1 Bridge Weigh-In-Motion System

A matched filter is obtained by convolving the unknown signal with a known signal or a conjugated time-reversed version of the template. The matched filter is the optimal linear filter for maximizing the signal to noise ratio in the presence of additive stochastic noise. Matched filters are commonly used in radar. More details of the matched filter can be found in [2]. This project investigated the use of the matched filter in detecting truck axles on the highway bridge.

In order to obtain the signals, a truck bridge interaction modeling [3] was created in the finite element environment as shown in Figure 1. LS-DYNA [4] was used to perform the finite element simulation.

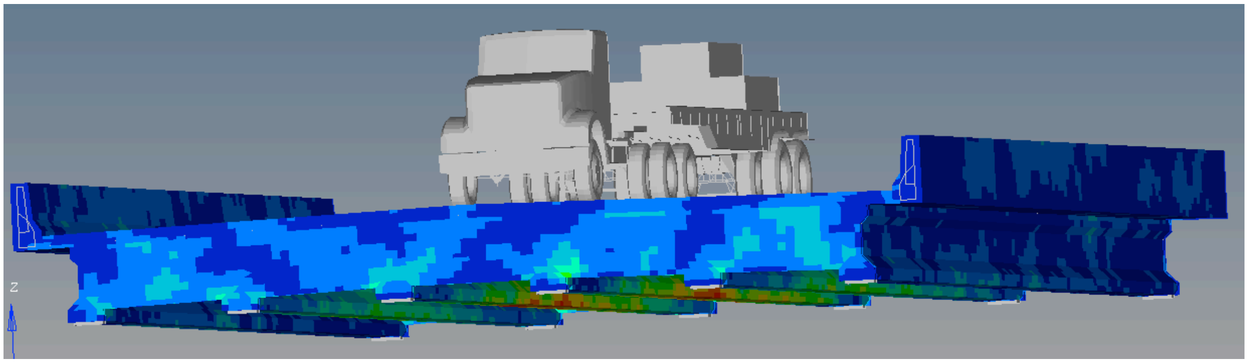
Figure 2 Truck bridge interaction modeling in LS-DYNA

The strain sensors were attached at the middle spot of each girder as shown in Figure 3. This bridge is considered to be a double lane and single direction bridge. Trucks are running from left to right. Because B2 and B5 are the most sensitive sensors to right lane and left lane traffic respectively, only information of the two sensors were discussed in this project.

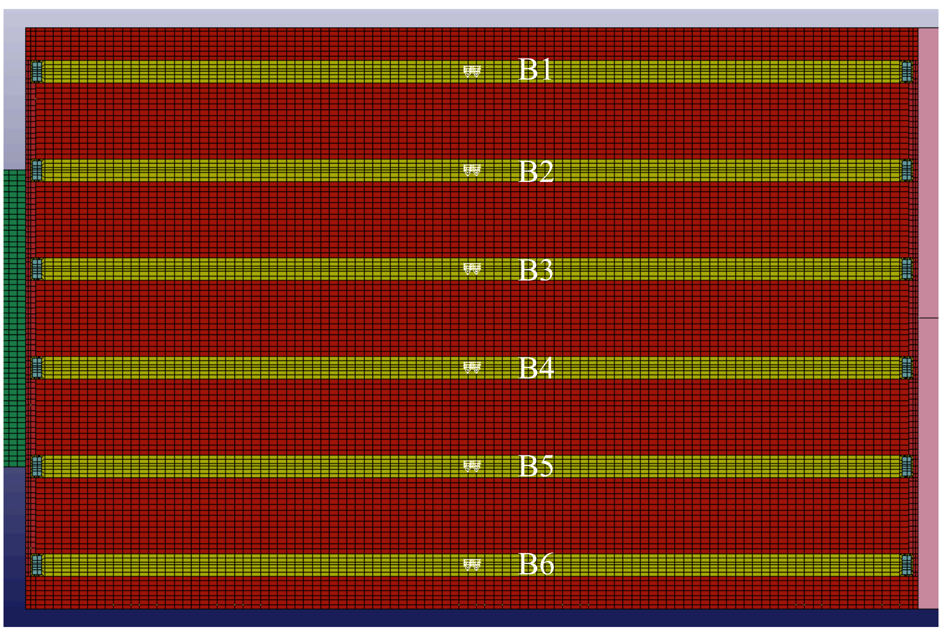

Figure 3 Sensors placement

Multi-presence of trucks on two lanes and truck weight and velocity are investigated in later paragraphs. For the sake of brevity, T1W1V5 stands for the control model; T1W1p5V5 stands for the model with 1.5 times weight of the concrete block on the back; T1W1V7 stands for the model with 70 mph velocity; T2L and T2R stand for the left truck and right truck respectively. The signal is also analyzed with 10% white Gaussian noise. Figure 4 shows the weight distribution of the normal weight truck and the truck with 1.5 times normal weight concrete block on the back. Because the concrete the only on the back of the truck, it affects the last two axles more.

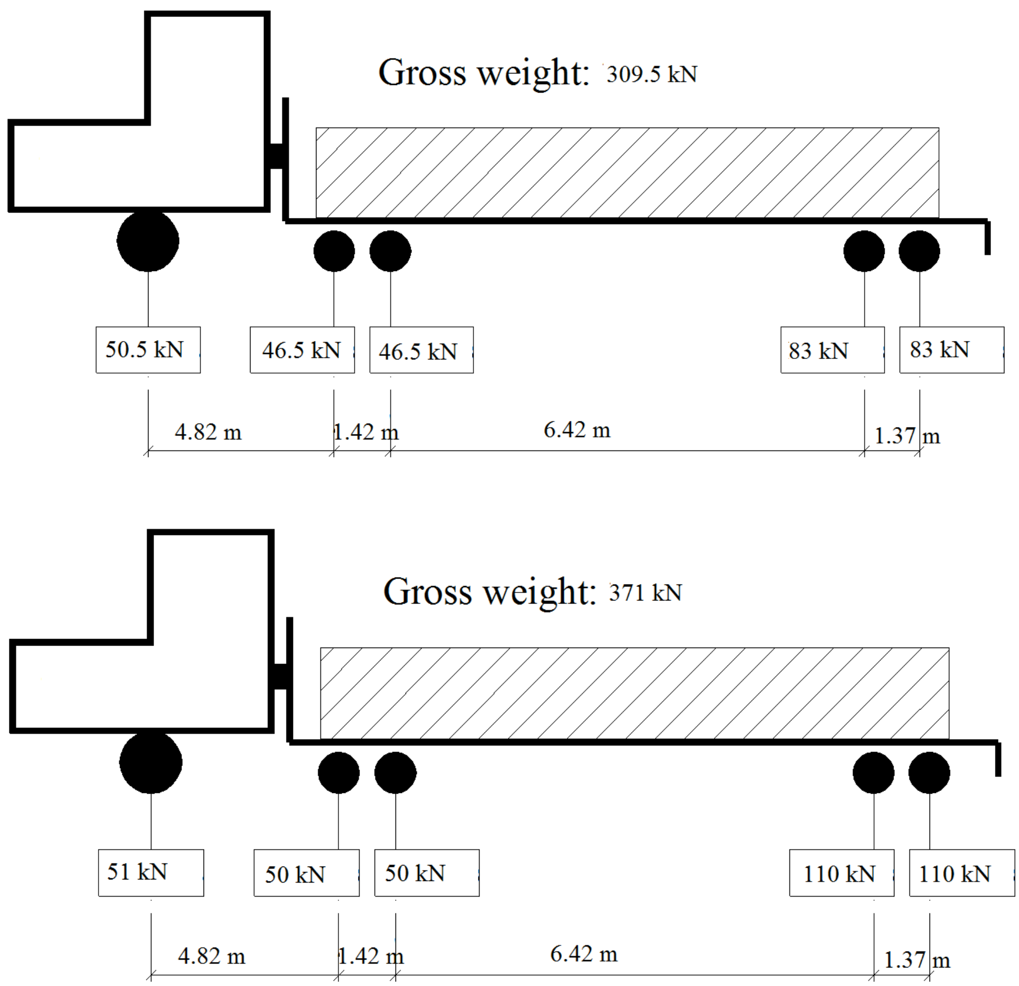

Figure 4 Trucks with normal weight and 1.5 times weight

Figure 5 shows the signal template for the matched filter. The template is a triangle normalized from the analysis of the truck signals.

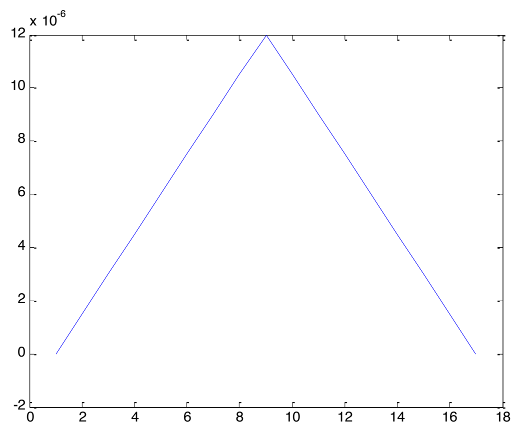

Figure 5 Signal template for the matched filter

RESULTS AND DISCUSSIONS

Figure 6 shows the result for the one truck running on the right of the bridge with normal weight and 50 mph velocity. The horizontal axis is not absolute time in seconds but time index. The bottom two shows the signal with addition of 10% white noise. The five peaks for the five axles are quite obvious even with 10% white noise. All the figures in this part were generated by the MatLab subroutine *matchedfilter.m*.

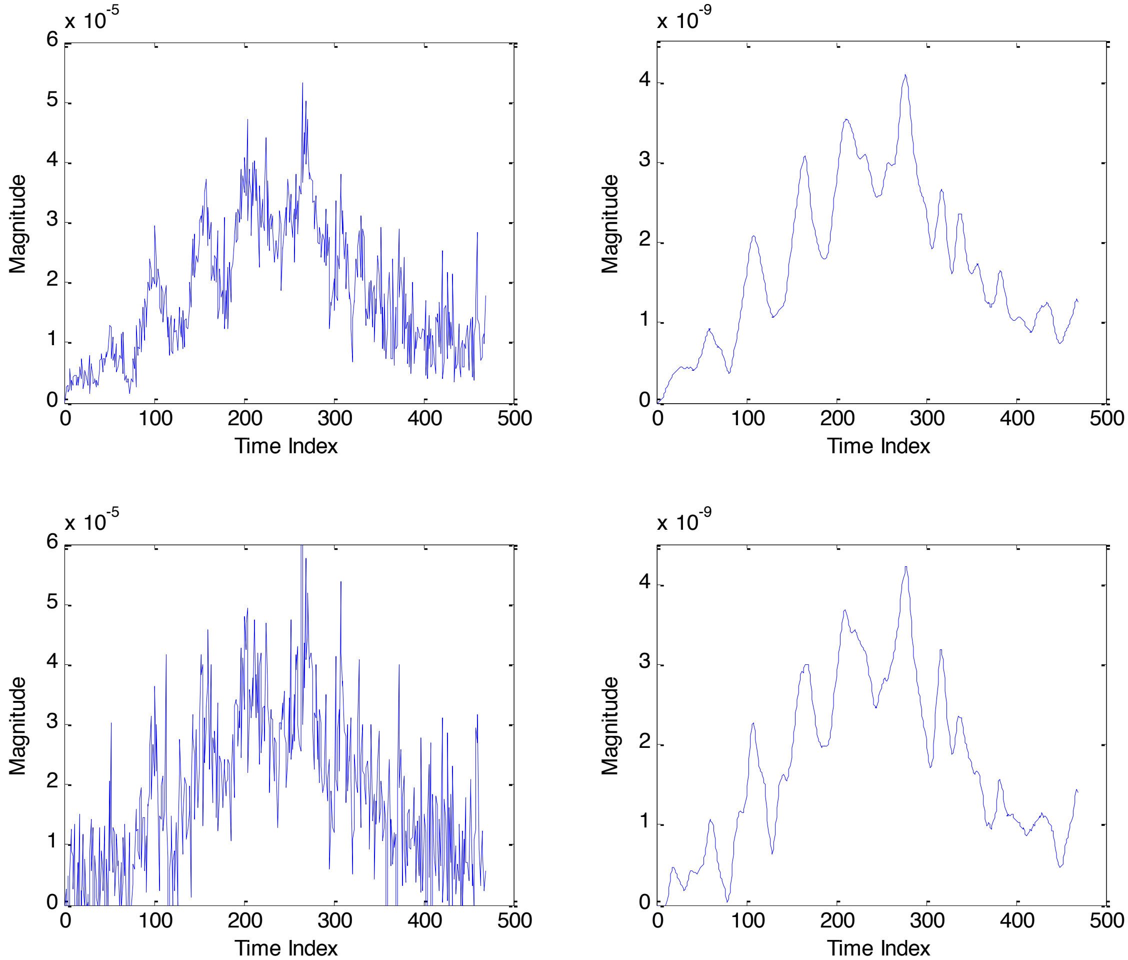

Figure 6 T1W1V5

Figure 7 shows the result for the one truck running on the right of the bridge with normal weight and 70 mph velocity. The five peaks in Figure 7 appear narrower than the peaks in Figure 6, because the truck runs 20 mph faster. The matched filter works well even with truck at the speed of 70 mph which is the normal speed in real highway bridge.

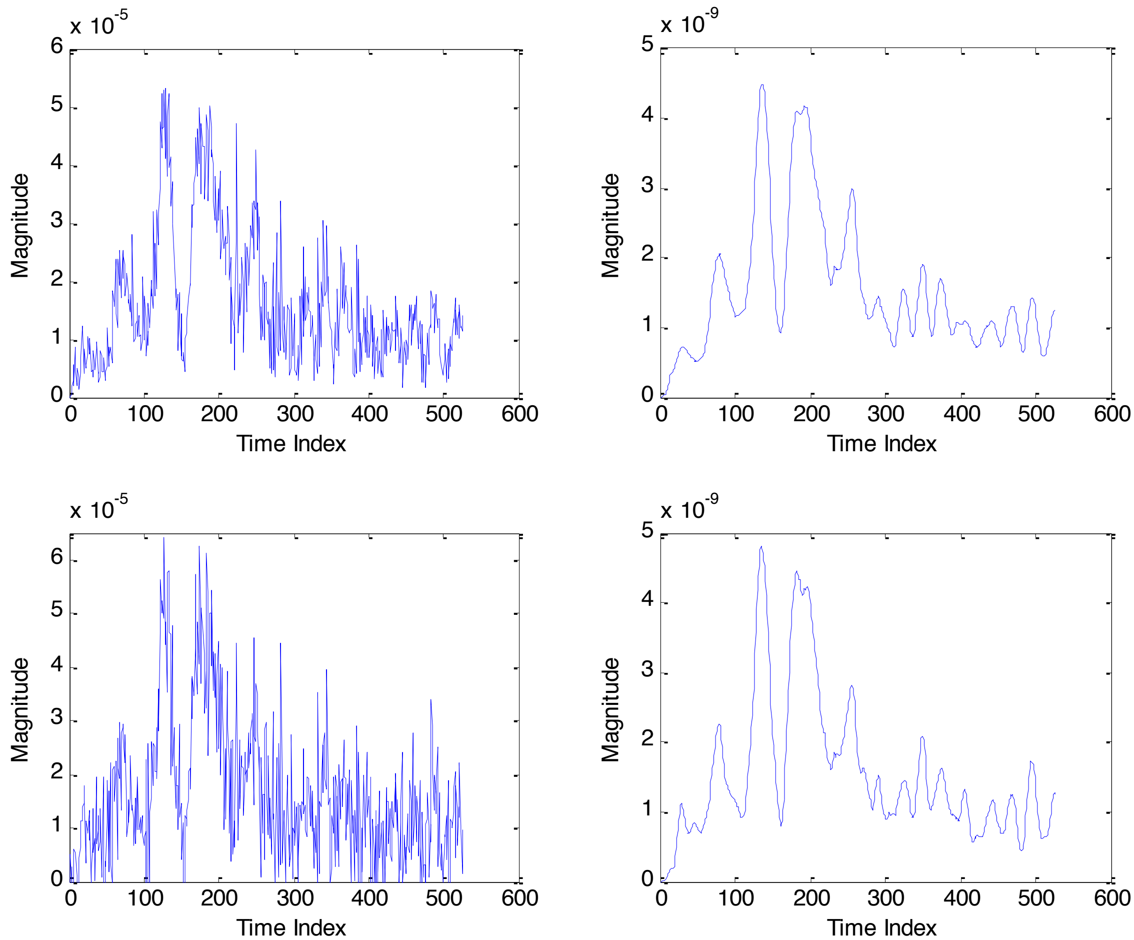

Figure 7 T1W1V7

Figure 8 shows the result for the truck running on the right of the bridge with 1.5 times of normal weight and 50 mph velocity. With more load on the back the magnitude of the peaks is higher than the ones with normal weight. The matched filter gives clears result of the axle numbers.

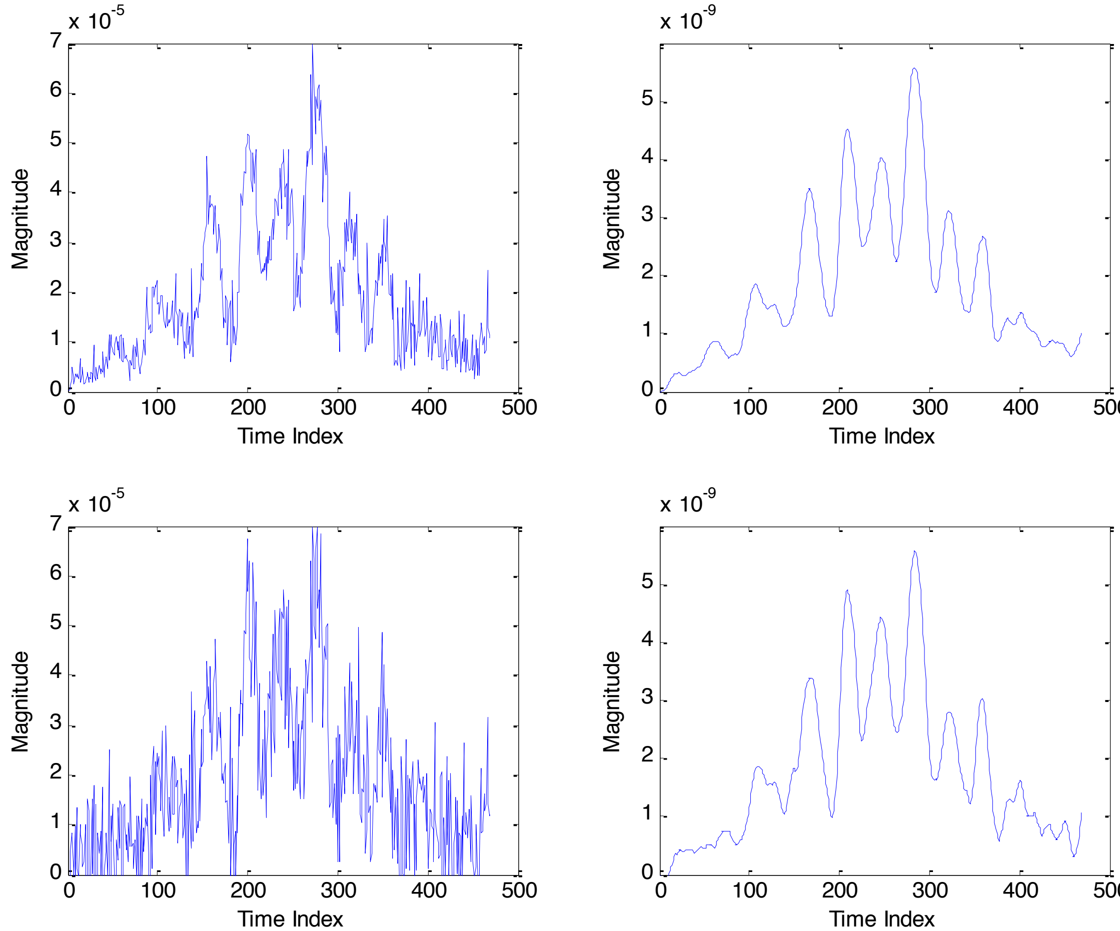

Figure 8 T1W1p5V5

Figures 9 and 10 simulate the real traffic scenario. Two trucks running on the highway bridge with the velocity of 50 mph and assuming no overpass in this short period, the right truck runs one-truck-length ahead of the left truck. T2R is for the right truck while T2L is for the left one. The right truck carries 1.5 times concrete block of the normal weight and the left truck carries the normal weight. The multi-presence scenario is a complex real life scenario. The matched filter does not work as well as for the previous single truck ones. Especially for the left truck which is running behind, the after-shock left by the previous truck is stacking with the vibration of the current running truck. The plot becomes spikier. But there are still reasonable peaks after filtering.

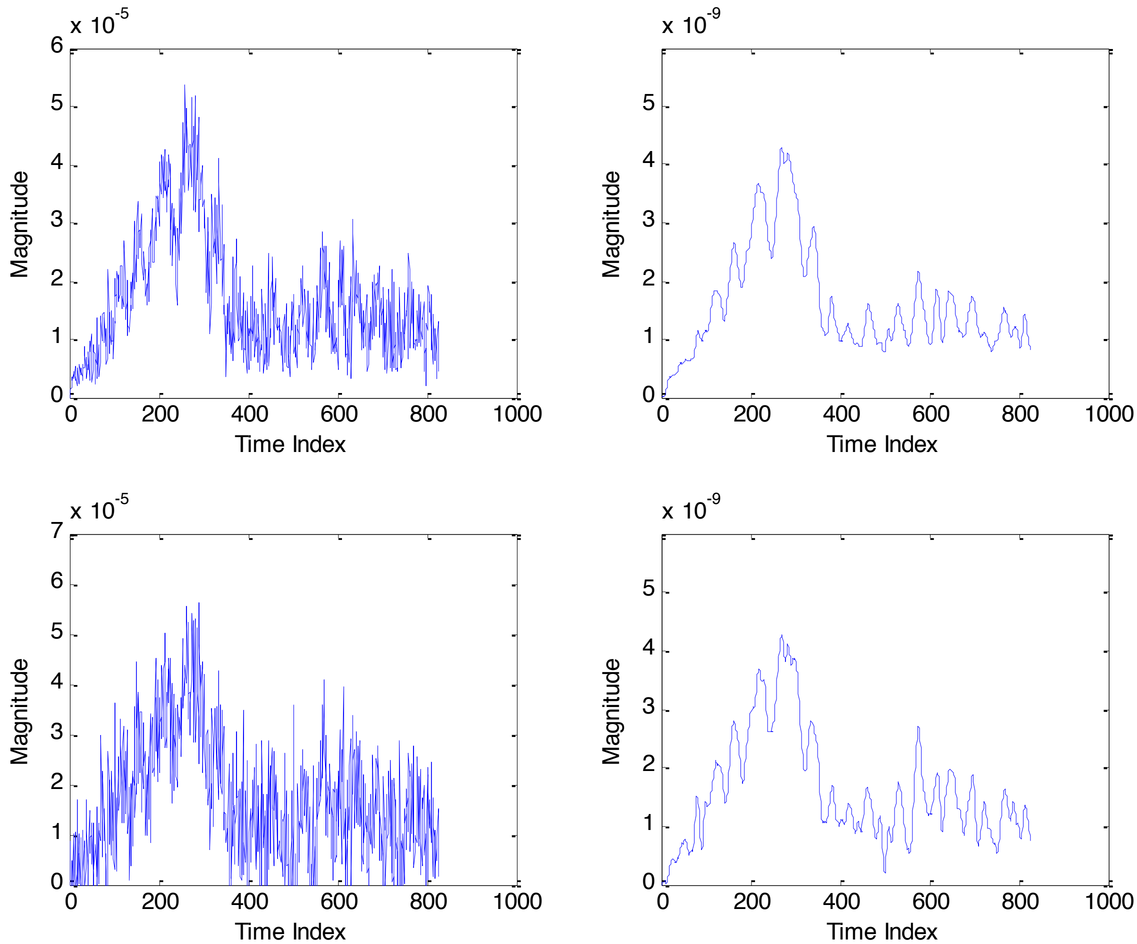

Figure 9 T2RW1p5V5

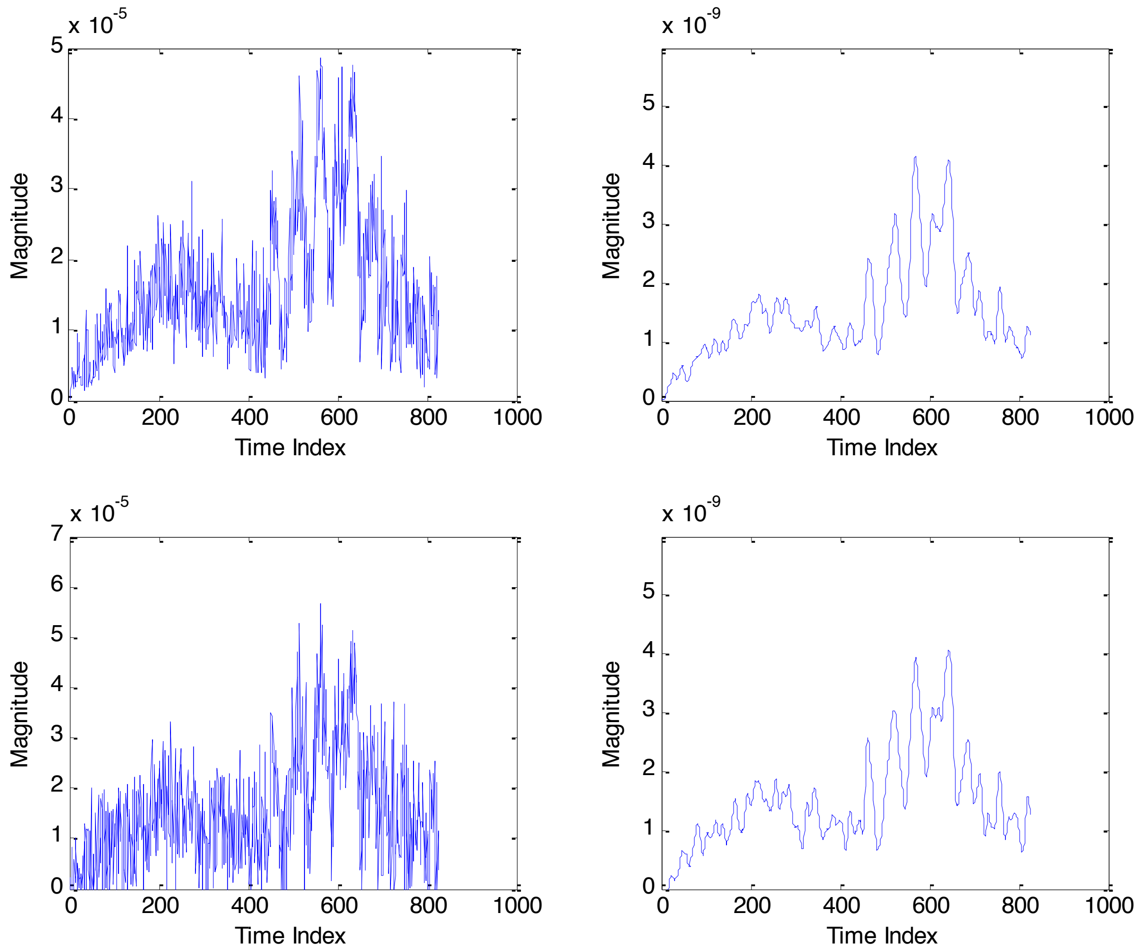

Figure 10 T2LW1p5V5

CONCLUSIONS

The matched filter proves to be an effective tool in detecting truck axles on the highway bridge. The use of the matched filter could make the current BWIM system more energy efficient, especially in the use of the wireless sensors where low battery consumption is a crucial requirement. Future efforts are expected to be put on looking for a better template signal other than the normalized triangle and more realistic finite element simulation trials.

REFERENCES

1. Zhao, Hua. "Bridge Weigh-In-Motion for bridge safety and maintenance." *Ph.D. Dissertation, University of Alabama at Birmingham, May 2010.*
2. Turin, George L. "An introduction to matched filters." *IRE Transactions on Information Theory* 6 (3) (June 1960): 311- 329.
3. Li, Hongyi. "Dynamic response of highway bridges subjected to heavy vehicles." *Ph.D. Dissertation, Florida State University, December 2005.*
4. LS-DYNA Version 971 Keyword User's Manual, 2006.