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PASSIVE SENSOR NETWORK RESYNCHRONIZATION APPLIED FOR SHM

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ABSTRACT

Recent research works in passive Structural Health Monitoring (SHM) have been able to take advantage of ambient noise by cross-correlating raw data recorded by sensor array. For that, the acquired signals must be synchronized with respect to each other. In other words, it is essential to set up a common clock to make this method successful. This significantly complicates the electronic setup and prevents moving towards an autonomous and wireless control network. As common solution, we propose here a technique of resynchronization in post-processing based on the study of the symmetry of correlation functions according to the physical characteristics of the considered medium. An in-depth analysis is conducted on the performance of this method in less favourable scenarios. Theoretical developments and experimental tests are carried out with the aim of emphasizing the quality of defect location according to the accuracy of resynchronization.

Keywords: *SHM, signal processing, cross-correlation, resynchronization.*

1. INTRODUCTION

Recently, it has been shown that the correlation of ambient noise field recorded by a network of sensors makes possible to reconstruct the Green's function of the medium [1, 2]. This has led to the possibility of passive monitoring of reverberant mediums. In other words, there is no need for a controlled emission and all the sensors are in passive listening. In [3], a passive imaging technique was developed. Indeed, the difference of correlation fields between a current state with and a reference state without defect makes possible to isolate the contribution of the latter. Thus, the back-propagation of the difference ensures the defect localization. However, this technique requires that signals recorded by the monitoring network be synchronized with each other. Possible instrumental shifts can significantly degrade the localization quality. One can opt for a common clock to ensure the synchronization. However, this absolutely complicates the electronic setup. An alternative solution is to establish the resynchronization only in post-processing. This imperatively requires an accurate estimation of time shifts between the different receivers of the surveillance network. Initially proposed in seismology [4, 5] and underwater acoustics [6–8], the correlation peak technique is a promising method for estimating inter-receiver time shifts. Indeed, after having calculated the cross-correlation between a pair of receivers, the correlation between its causal and anti-causal parts gives a peak of resemblance corresponding to the double of the time shift between these receivers.

In this paper, we are initially interested in highlighting the impact of time shift on the defect localization quality. Then a-posteriori resynchronization based on the peak correlation method is established. Finally, the obtained experimental results are discussed.

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2. IMPACT OF SHIFT TIME ON THE DEFECT QUALITY LOCALIZATION

To highlight the effect of inter-receiver time shifts on the defect quality localization in a reverberant plate, the configuration represented in Fig. 1 is experimentally tested. That concerns an aluminium plate of $1m \times 0.5m \times 3mm$ dimensions on which 8 PZT receivers noted $R_{1 \leq i \leq 8}$ are placed. An acquisition board (24 I/O MOTU, 192kS/s, 24 bits) is used for acquiring data. A diffuse acoustic field is generated by rubbing over the plate surface. To compensate the temporal fluctuations, the amplitude of the envelope of time-dependent noise is normalized to compensate the temporal fluctuations. Also, a frequency whitening is performed on the obtained signals between 1 and 30 kHz. A magnet is placed at $(0.5m, 0.26m)$ to create a change of material is used as a defect. The passive imaging technique described in [1] allows the defect localization by taking advantage of the cross-correlation of the generated acoustic field. In order to emphasize the impact of the desynchronization on the defect localization quality, random shifts $\sim \mathcal{N}(\mu = 0, \sigma = 100T_s)$ are introduced on the 8 receivers. Where $T_s = 5.2\mu s$ is the sampling period. In Fig.2b, it clearly appears that the exact position of the defect is ambiguous because of the introduced offsets. Nevertheless, this defect is perfectly localized when the signals are synchronized (see Fig. 2a, witness case).

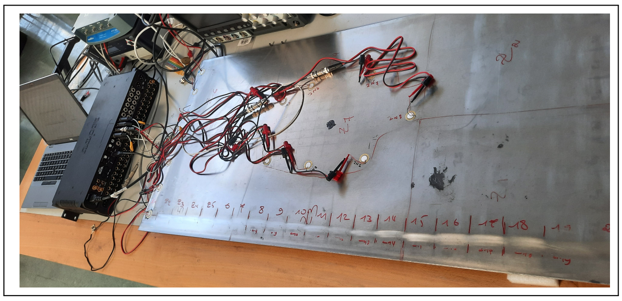
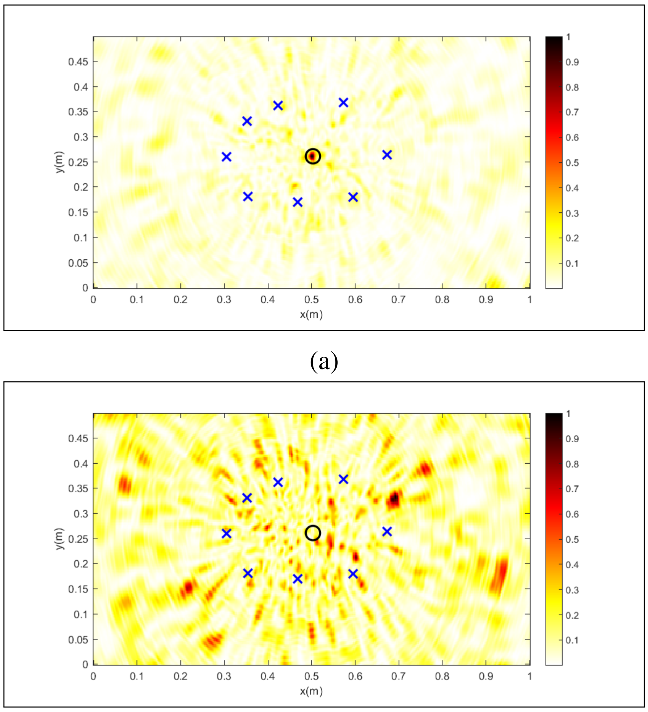


Figure 1: Experimental setup.

To quantify the impact of inter-receiver time shifts on the defect localization, we are interested in evaluating the variation of its contrast as a function of the standard deviation of introduced shifts using the classical contrast formula given by [9] :

$$C = \frac{I_d - I_b}{I_b}, \tag{1}$$

where C is the contrast, I_d and I_b designate respectively the defect and the background (excluding the defect area) intensities as defined in [1]. Time offsets with standard deviations varying between 0 and $15T_s$ are introduced on the 8 receivers. For each standard deviation, 20 iterations are performed and the average contrast is recovered. Obtained result is shown in Fig. 3.



(a)

(b)

Figure 2: Defect localization images in the case of (a) synchronized (b) non-synchronized signals. Blue crosses represent the receivers and the black circle the defect position.

Thus, the obtained pattern can be broken down into 3 parts: for zero standard deviation shifts (synchronized signals) the defect is perfectly localized. For a standard deviation varying between 1 and 10 samples, the defect is always localized but with secondary lobes which disturb the localization ($C > 1$). From $\sigma = 8Ts$ the defect position is completely ambiguous ($C < 1$).

3. POST-PROCESSING RESYNCHRONIZATION OF SHIFTED SIGNALS

In this section we are interested in the estimation of time shifts between sensors. These shifts are to be compensated

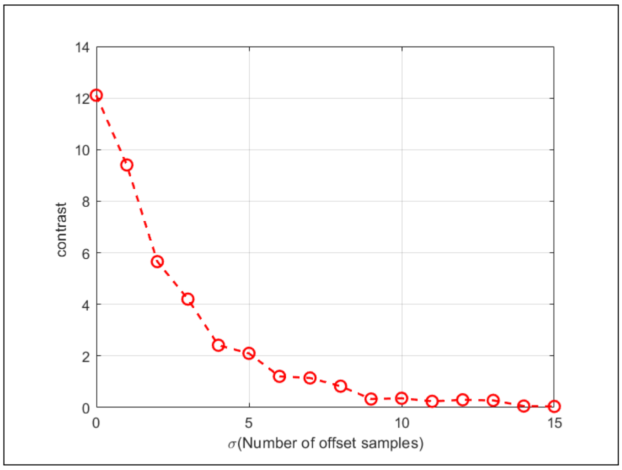


Figure 3: Defect contrast in function of offset standard deviation.

to ensure a post-processing resynchronization.

3.1 Description of the synchronization method

Let us consider a general case with N_r receivers. The time shift $\delta_{i,j}$ between a given pair R_i and R_j can be expressed as follows :

$$\delta_{i,j} = \Delta_i - \Delta_j, \tag{2}$$

where, Δ_i and Δ_j are the time offsets specific to R_i and R_j respectively.

The whole time shifts between the Nr receivers can be expressed through the following matrix system:

$$M\Delta = \delta \tag{3}$$

M is a connectivity matrix containing 0, 1 or -1 according to Eq. 2. Δ is the vector of unknowns (offsets specific to each receiver), and δ is a vector containing the shifts between all possible pairs. As mentioned in the introduction, these shifts are estimated using the peak correlation method. We note that the matrix M is not invertible. Therefore, the time shifts will be recovered via an approximate solution using the Moore-Penrose pseudo inverse of M denoted M^+ [10].

$$\Delta = M^+\delta \tag{4}$$

The estimated offsets are to be compensated. Thus, the receivers will be resynchronized only in post-processing.

3.2 Results and discussion

We opt for the experimental configuration represented in Fig. 1. On the signals recorded by the 8 receivers, random offsets $\sim \mathcal{N}(\mu = 0, \sigma = 500\ T_s)$ are introduced. So that we are sure that the desynchronization introduced is largely sufficient to prevent the defect localization. The shape of recorded signals after the introduction of random shifts is represented in Fig. 5a.
For this study, there are 28 different combinations of 2 receivers. The cross-correlation of the noise field is calculated for each pair. The correlation peak between its causal and anti-causal parts allows obtaining the time shift between each receiver combination. Thus Eq. 4 makes possible to estimate the specific offset of each receiver. As shown in Fig. 4, the estimated shifts are in excellent agreement with the introduced ones.

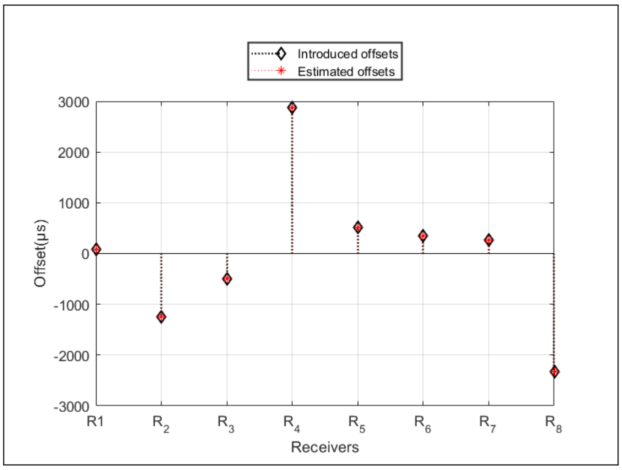
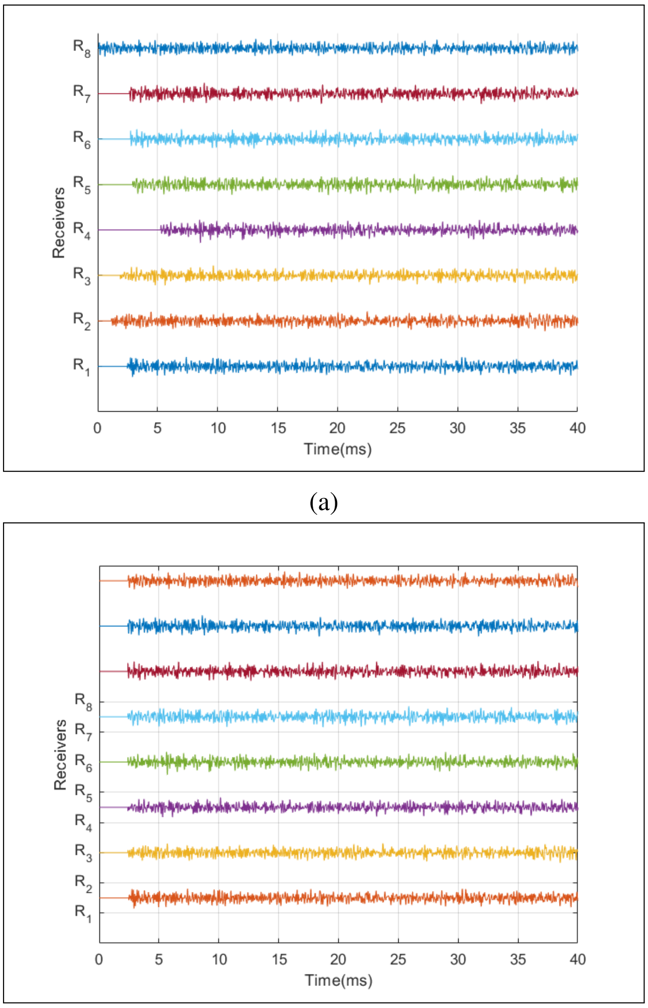


Figure 4: Comparison between introduced (black triangles) and estimated (red stars) time offsets.

Thus, by compensating the time shifts of the signals, all the receivers are resynchronized as shown in Fig. 5b.

4. CONCLUSION

In the present work, the effect of the desynchronization of a sensor network dedicated to the SHM has been studied. As much as it is necessary to ensure defect location, resynchronization has to be done in post-processing to avoid complicating the monitoring electronic system. Based on the correlation peak method, the developed synchronization algorithm allowed to obtain promising results. Further, this will effectively makes possible to do the SHM



(a)

(b)

Figure 5: Signals (a) before and (b) after a-posteriori resynchronization.

using a network of independent sensors.

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