Structural Health Monitoring using time reversal techniques in acoustic domains

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Abstract

An increasing interest for Structure Health Monitoring (SHM) has been observed during the last decades. Monitoring solutions have then been developed to detect flaws in structure at an early stage in order to anticipate on maintenance. In this paper, focus have been made on time reversal techniques in acoustic domain (up to 10kHz). Devices suitable for in field instrumentation have been developed and have shown good results for sub-wavelength sized flaw detection.

1 Introduction

In the 80s, M.Fink [1] demonstrated the ability of linear systems to go back to their initial condition. One practical application of this property, so-called Time Reversal (TR), is the possibility to create virtual shocks in structures. To do so, a first phase of learning is needed: The structure is impacted at some point A. At other points $B_1 ... B_n$, the signals due to this impact are measured with transducers. In a second phase, the measured signals at $B_1 .. B_n$ are played back from end to beginning, leading to the appearance of an impulse at point A. This second phase is known as focalization. This property has been used in several domains such as lithotripsie [2] or telecommunication [3, 4], mostly in ultrasonic, or higher, frequency range.

One interesting feature of time reversal techniques is their sensitivity to structure modification: as soon as the structure is modified. Whereas traditional techniques are limited by diffraction limit at size $\lambda/2$, time reversal methods have shown sensitivity to subwavelength sized flaws. In [5], experimental studies show sensitivity to $\lambda/7$ flaws. Numerical studies let even expect better sensitivity, up to $\lambda/14$ [6, 7].

It appears then interesting to investigate the usability of time reversal methods (TRM) for structure health monitoring (SHM). In particular, in this study, the subwavelength sensitivity allowed us to use TRM in acoustic frequency domain in order to benefit from long range (tens of meter) propagation properties of such waves.

Focused have been made on making TRM applicable to industrial cases. Devices allowing easy in field time reversal experiments and data processing have been designed. Experiments on typical industrial structures have been led allowing to validate the ability of the devices to create focused signals and exhibit suwavelength sensitivity.

2 Experiments

2.1 Devices

Realization of TR experiments need an acquisition chain and a sensor that is also ideally able to be reversed and emit a signal. One goal of this study was to design a portable device to do so.

- The transducer rely on piezoelectric technology with a simple seismic mass system achieving a sensitivity of $10nC/g$. and a first eigen mode at $5kHz$.

- The data acquisition chain is built with an on-board computer associated with audio DAC/ADC and a few analogical components such as charge and power amplifiers for the piezoelectric transducer. This device has a frequency range of $10Hz$ to $20kHz$ acquiring signal filtered at $10kHz$.

In order to ease learning phase, given that Dirac function is not achievable with a piezoelectric ceramic, one of the device emit a down-chirp signal from $10kHz$ to $10Hz$. The second one measure the response and compute the theoretical impulse response by correcting the phase. This corrected signal is then reversed and used for focalization experiments. On the wire-mesh structure, learning was also made near the accelerometer with a shock hammer. The measured signal is then reversed and used directly for focalization phase.

Two such devices have been built to do TR focalization from one device to another. This is quite a low amount of re-emitting devices. As a consequence, both learning method and one device TRM will need to be demonstrated to show the system focalization ability.

2.2 Studied Structures

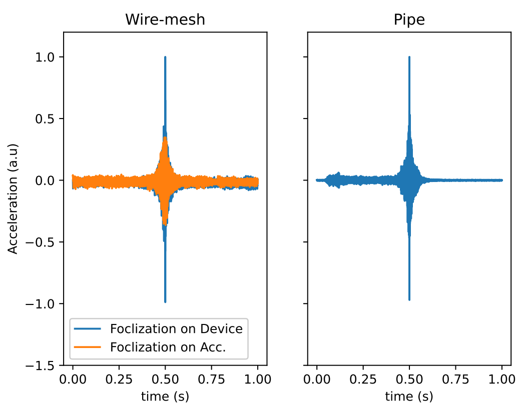
Experiments have been led on two different structures:

- First, a supporting steel wire-mesh has been instrumented. The two devices have been placed on two different beams on the structure. In this experiment, a supplementary accelerometer was also placed on the structure.
- A steel pipe has also been instrumented. The two devices were placed at 12m from one another. More over, the pipe is clamped between the two devices (at 1m from one of them) by a concrete wall.

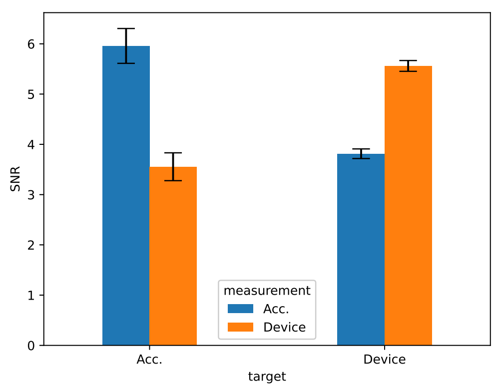
For each structure, a learning phase is first done. Then 3 focalization are realized on the unchanged structure. Those experiments are named FOC. Flaws are then emulated by adding a 16g, 54g and 900g magnetic mass on the structure. For each one, 3 focalizations are realized. Those experiments are respectively named M16, M54 and M900. Finaly all masses are removed and 3 focalizations are done once again. Those experiments are named RET (return to normal). On the wire-mesh structure, this experiment series is done for each of the learning signals. On steel structure, with 10kHz signals, minimal wavelength is $\lambda/2 = c/(2f) = 28cm$. All masses have smaller diameter (resp 1.5cm, 3cm and 7cm).

3 Results and discussion

3.1 Focalization ability



(a) Temporal representation of focalization phase for the two experimental set-up (wire-mesh on left graph, pipe on right graph)



(b) Signal to noise ratio of focalizations between the targeted point and the other sensor for wire-mesh experiments

Figure 1: Focalization ability

First on the Figure 1a, temporal signal for FOC phase measured by devices on both wire-mesh and pipe structure are shown in blue. For both, a clear emergence appear at the center of the focalization signal. For the wire-mesh structure, on the left graph of Figure 1a, the signal measured by the device while focalizating on the accelerometer is also shown and exhibit a much smaller peak at focalization instant. Those temporal results tend to confirm that devices are able to focalize on the point for which learning was done.

In order to confirm those results the mean signal to noise ratio (SNR) was computed for all the FOC and RET experiments of the wire-mesh stucture. Those results are shown in Figure 1b: on the left, the mean snr of the device (blue) and accelerometer (orange) signals while focalizing on the device are shown, on the right, the mean SNR of the device (blue) and accelerometer signals (orange) while focalizing on the accelerometer are shown. The SNR of the targeted sensor is systematically 1.5 times higher the SNR of the other. These results tend to prove that the peak signal observed at the targeted sensor is focalization signal and then validate both one device TRM and Learning method.

3.2 Flaw detection

On the Figure 2, mean SNR of the focalization experiments are plotted for the two experimental setups. For both setups, SNR for FOC and RET experiments are quite similar while experiments with addded mass have a significantly lower SNR. On the wire-mesh set-up, SNR grows as added mass decreases exhibiting an expected behavior. For the pipe set-up, such behavior isn't observed for the larger mass but still stand for other experiments. These can either indicate a poor quality of SNR as indicator or poor coupling condition between the large mass and the pipe.

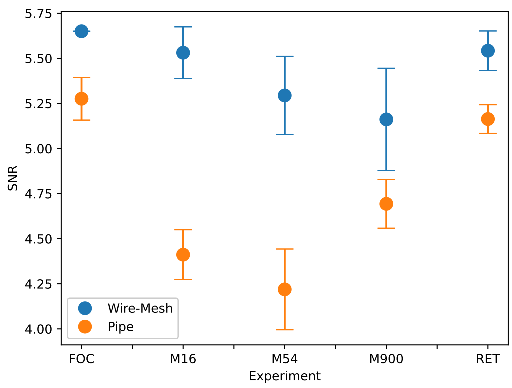


Figure 2: The logo of the SURVISHNO International Conference

4 Conclusion

Compact and portable devices have been designed and used on different structures. Those devices where able to produce good quality focalization and flaws with sub-wavelength size have been detected. Those results offer interesting perspectives for the use of TRM in acoustic domain for SHM. However progress has to be done in order to give good indicators of flaws magnitude. To do so, numerical studies of under control structure could be of great help to determine how flaws affect various properties of focalization signals and then be able to determine an optimal indicator for SHM purpose. With even more accuracy in modeling, numerical learning phase could even be achieved.

Acknowledgements

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