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# Feasibility of passive tomography of extended defects using ambient elastic noise correlation

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**Abstract**

Using guided waves in structural health monitoring seems interesting because of their capability to propagate over long distances. This paper shows that tomography algorithms using guided waves in plate-like structures and cross-correlation of ambient noise can be combined to process the passive tomography of a structure. This can make a very robust and low power SHM system. An active tomography image has been performed with a time-of-flight tomography algorithm using experimental data produced by piezoelectric transducers. Comparison between active signals and passive signals which come from cross-correlation of ambient noise produced by compressed air sprayed on an aluminum plate shows that it is possible to detect time-of-flight passively.
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*Keywords:* Structural Health Monitoring, Tomography, Cross-Correlation, Guided Wave, Experimental Images

## 1. Introduction

Structural health monitoring (SHM) consists in the embedding of sensors in a structure such as an aircraft or a naval ship in order to detect defects (for example cracks or corrosion in metallic materials or delamination in composite materials) before a serious fault occurs in the structure. In aeronautics, the classical approach generally aims at minimizing the number of sensors to limit the embedded mass as well as the sensors intrusiveness within the structure. Comparisons between current signals and baseline signals are often performed in order to reveal the presence of defects ([1]). However, this method may not be robust under certain conditions such as changes in temperature, stress, sensors aging, etc. Using tomography algorithms by increasing the number of sensors allows avoiding the use of these baseline signals. By doing so, more physical information is obtained and tomography algorithms produce images that are much easier to understand than temporal signals.

Guided elastic waves emitted by a sensor and propagating to another one are often used as the physical way to detect defects. However, the implementation of SHM systems is restricted in many situations by the amount of electric power necessary to emit waves. A promising way to tackle this constraint is to use techniques based on cross-correlation of the ambient acoustic noise present in the structure. It has been shown that, under certain conditions,

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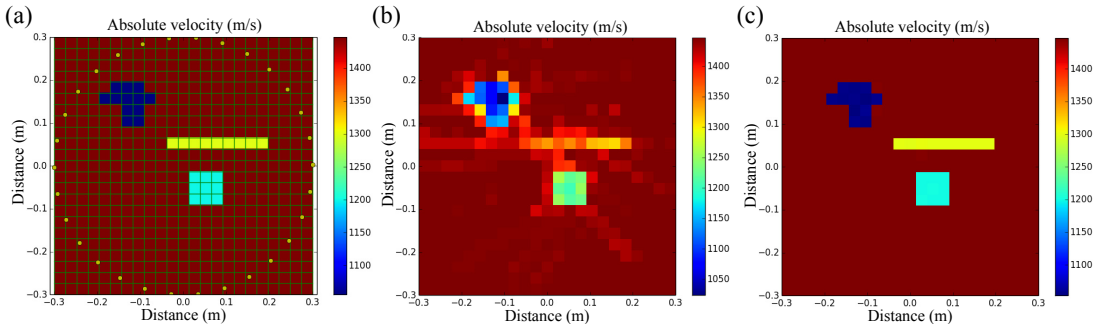


Fig. 1. (a) Configuration; (b) Result after 1 iteration (no smoothing); (c) Result after 30 iterations (no smoothing).

transient response between two sensors can be passively estimated from the cross-correlation of ambient noise ([2], [3], [4]). The idea is to take advantage of the elastic noise naturally present in the structure (due to engine vibrations or aero-acoustic turbulences on the fuselage of an aircraft for example) in order to avoid the emission of the elastic waves by the SHM system.

This paper shows an active tomography image which has been performed with a time-of-flight tomography algorithm using experimental data produced by piezoelectric transducers. Furthermore, a comparison between active signals and passive signals which come from cross-correlation of ambient noise produced by compressed air sprayed on an aluminum plate shows that it is possible to detect time-of-flight passively. Section 2 explains which tomography algorithm is used. Section 3 specifies the devices - composing the experimental bench - used to acquire the data necessary to obtain the image of section 4. Section 5 shows that it is possible to use cross-correlation of ambient noise present in the plate-like structure to get the data required for the tomography algorithm.

## 2. Time-of-flight tomography algorithm

Images shown in this paper are obtained with a time-of-flight tomography algorithm which uses the Simultaneous Iterative Reconstructive Technique (SIRT) ([5]). Straight ray assumption is taken within this framework. Straight ray tomography does not take into account refraction and diffraction. By ignoring diffraction, only defect bigger than the first Fresnel zone ([6]) and varying slowly are correctly reconstructed. By ignoring refraction the algorithm is limited to low contrast flaws. Better algorithms that take into account refraction and diffraction exist ([7]) and will be studied in future works.

A simulation respecting these assumptions (i.e. no refraction and diffraction) has been made (see Figure 1). The configuration on Figure 1a shows 30 sensors which are symbolized by yellow points, 23 x 23 pixels and three different defects. Input data is a set of time-of-flight deducted from dispersion curves of A0 mode at 30 kHz propagating in a plate of 2 mm thickness. The absolute group velocity is 1447 m/s when waves propagate in the healthy part of the plate and 1300 m/s, 1200 m/s and 1056 m/s when they propagate in defects (i.e. zone of reduced thickness $\approx$ corrosion). The figures 1b and 1c show that the more the number of iterations increases, the more the time-of-flight tomography algorithm converges toward the exact velocity map. In practice, image smoothing is interesting since corrosion and pixels will never be superimposed on each other. That is why the experimental image on Figure 3b of Section 4 is smoothed by performing an interpolation by splines.

## 3. Experimental setup

The time-of-flight algorithm in the Section 2 helped, among others things, to design an experimental bench (see Figure 2). The bench is composed of a computer with a LabView program which controls an oscilloscope and a multiplexer; a generator which is synchronized with the oscilloscope thanks to a trigger; an amplifier; a filter and finally the piezoelectric transducers stuck on a 2 mm thick aluminum plate. Phenyl salicylate (SALOL) is used to

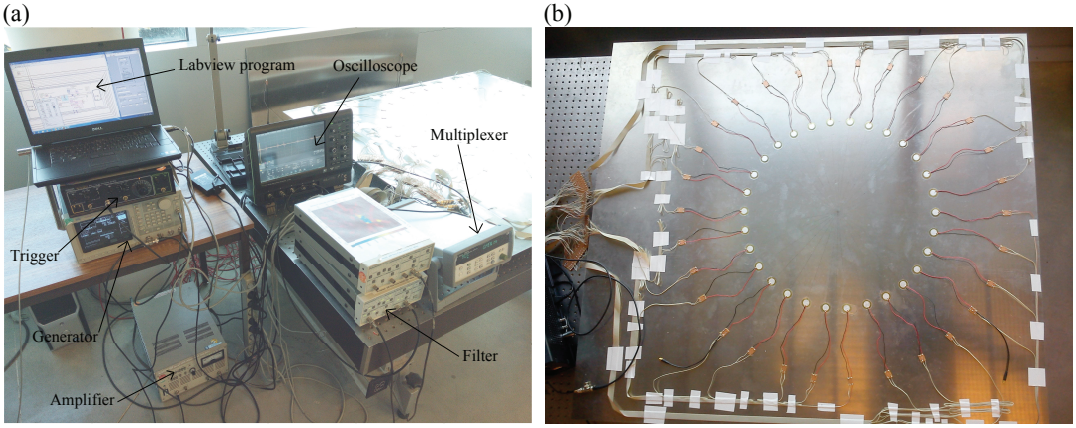


Fig. 2. (a) Experimental setup; (b) 30 piezoelectric transducers (∅ 18 mm) stuck on the 2 mm thick aluminum plate

bond localized thin calibrated aluminum layers on the plate. This type of defect is not corrosion, but, in practice, the fact that it can be easily removed is interesting.

## 4. Active experimental image

Figure 3 shows an experimental active absolute time-of-flight tomography image (Figure 3b) which results from the algorithm of Section 2. Reversible flaws (Figure 3a) were used by adding a thin aluminum plate glued (with SALOL) on the plate to be inspected. 'Absolute tomography' means that data only comes from current signals. This way, the method should be quite robust as baseline signals are never used. Input data was obtained by emitting a 1.5 cycle tone-burst at 177.5 kHz. Time-of-flights from first S0 wave packet were identified by the algorithm for each couple of sensors. The two flaws of Figure 3a are easily distinguishable on Figure 3b. There were punctual adhesive absences between aluminum plates, zones with poor adhesion of SALOL and variabilities in the thickness of the SALOL. All of those reasons explain partly why the reconstructed defects do not follow exactly the real key lines of rectangular and circular aluminum plates.

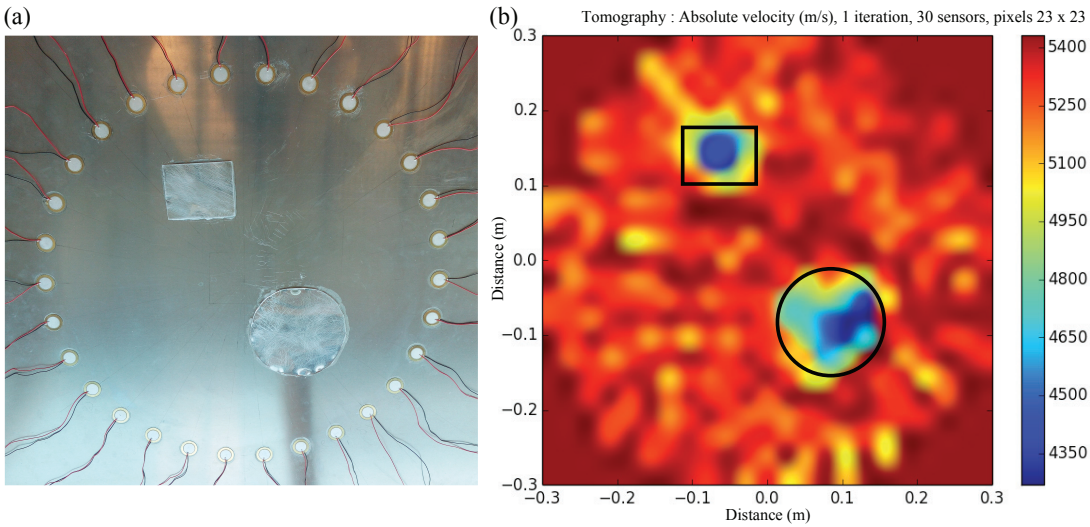


Fig. 3. (a) Experimental configuration; (b) Absolute time-of-flight tomography (smoothed velocity map)

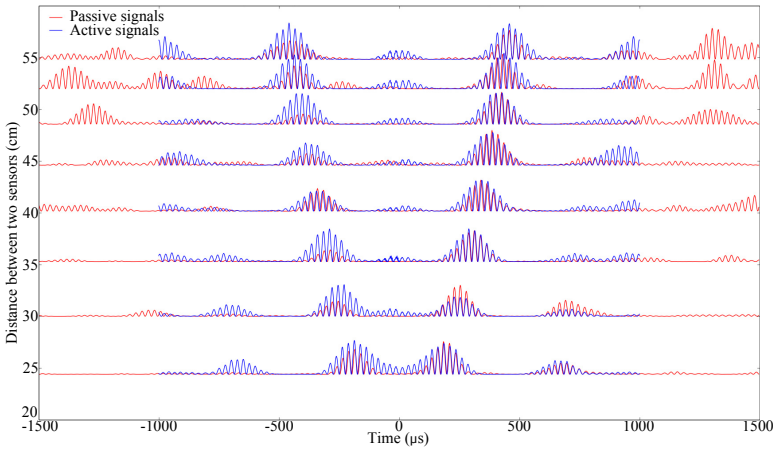


Fig. 4. Comparison between active and cross-correlation signals

## 5. Active and passive signals comparison

Input data necessary to obtain the images of Sections 2 and 4 was a set of time-of-flight. This Sections aim at knowing if this kind of data can be obtained on passive signals. That is why a comparison between active and passive signals (cross-correlation of ambient elastic noise) is presented here on Figure 4. 8 cycles tone-burst at 20 kHz were generated in order to obtain the active signals. The elastic noise used for the cross-correlation was produced by spraying compressed air on the plate surface. The absolute values of those signals are plotted on Figure 4 for several distances between sensors. This way, the propagation of the first wave packet is shown for each active signal. Passive signals show a satisfactory reconstruction of Green's functions at least for the first wave packet. Indeed, the result is symmetrical and first wave packets are adequately superimposed on passive and active signals. It is therefore possible to get time-of-flight from passive signals. This is a reason to think that passive tomography is promising. Other results not presented here show that this passive extraction of time-of-flights is feasible at higher frequencies.

## 6. Conclusion

This paper has shown that it is possible to image defects experimentally by using piezoelectric transducers thanks to a time-of-flight tomography algorithm. Active experimental tomography using ballistic guided waves data was performed in this paper. It was also shown that it is possible to detect time-of-flight by using cross-correlation. That is why passive experimental tomography seems to be promising.

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