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Microphone Based System for Visualization of Vibration Patterns

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Summary:
An acoustic system for measurement and visualization of surface vibrations is described. Based on pressure gradient probes implemented with low-cost MEMS microphones, the system features highly parallel signal processing using low performance cores. Currently, the validation of the proposed method is ongoing. Presented results demonstrate the fundamental functionality of the system both for stationary and transient processes.

Keywords: contactless vibration visualization, microphone array

Introduction

Visualization of surface vibrations is of interest e.g. in structural health monitoring [1] or in investigations of musical instruments [2]. It can be accomplished in different ways, including Chladni powder patterns, speckle pattern interferometry and laser vibrometry to name a few. The methods have their own advantages and limitations and differ in the necessary instrumentation effort. The proposed visualization method targets applications where primarily the vibration pattern itself is of interest, whereas the absolute value of surface dislocation is secondary. It is based on acoustic measurement to allow a contactless acquisition of surface vibrations. The goal is to avoid sequential surface scanning and to be able to capture the propagating surface waves after a single excitation.

Near-Field Acoustic Holography (NAH) was shown to deliver surface vibration patterns in quasi stationary processes [3]. The method described here is based on the two-microphone technique [4], it differs from NAH in several basic aspects and potentially allows observing wave propagation. Two existing versions of system design feature parallel signal processing using microcontrollers, they rely on miniature MEMS microphones and target low hardware cost. Presently, the validation of the method is ongoing based on the system design described below. The current goals are the verification of the results and the defining the region of applicability of the method.

Measurement Principle and System Setup

The implemented system contains a number of measurement channels designed as pressure gradient probes with two closely spaced MEMS microphones (Fig. 1a). As the pressure gradient is proportional to the time derivative of particle velocity (Euler equation), its double integral leads to the particle displacement. Under the assumption that the object surface translates its motion into the motion of the air particles, the orthogonal component of the pressure gradient contains information about the surface motion. The approximation of the full vibration pattern is made by interpolating the measured surface displacements between the channel positions. This approach allows parallel processing of microphone signals up to the point where all data must be combined for visualization. Key advantages of the processing algorithm are simplicity and stability. The requirements on the single processing cores are drastically reduced on the cost of their number.

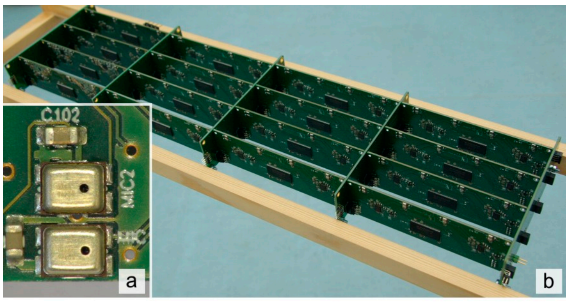

Fig. 1. (a) A close-up view of a measurement channel. Spacing between the microphone input ports is 3 mm. (b) The tested system with 64 channels.

The measurement system consists of identical sensor boards, several connector boards to set up a sensor array and a master board which controls the measurement process and transfers the results to a PC. Each sensor board

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contains four measurement channels and a microcontroller to process the signals. The microphone pairs are mounted close to the PCB edge, which is directed towards the object surface during the measurement. The current design of the system targets measurements on more or less planar objects.

The results presented below were acquired with a 64-channel system arranged in a 16 by 4 matrix (30 mm channel spacing) covering a 450 × 90 mm² area (Fig. 1b). Each sensor board carries eight consumer-grade MEMS microphones and two audio ADC ICs. The AD conversion of the audio signals is performed with 16-bit resolution at 48 kSps. The boards can store measurement sequences of up to 43 s duration.

Results and Discussion

Selected results reproduced here originate from validation tests in stationary and transient cases. Fig. 2 shows a stationary situation, where the system was placed horizontally 10 mm above a shaker platform of 72 mm diameter which was driven with an amplitude of 5 µm in vertical direction by a sine signal with f = 500 Hz. For every channel (small black circles in Fig. 2) surface displacements are calculated and then interpolated by piecewise cubic Hermite polynomials. The three frames are taken from the continuous data stream with intervals of 500 µs to illustrate one half period of oscillation. A reasonable reproduction of the platform movement can be observed with an obvious restriction on minimum detectable features due to the sampling in space domain.

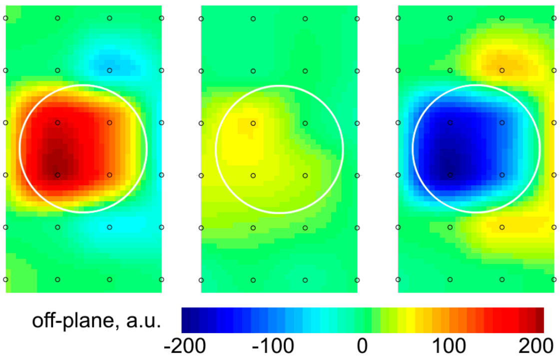

Fig. 2. Color coded off-plane displacements of a vibrating shaker platform (white circle). The black circles show positions of measurement channels.

In Fig. 3a the wave propagating in a carbon-fiber-reinforced polymer (CFRP) plate after a minor hit with a plastic pen in its center is shown. The plate (400 mm × 132 mm, 10 mm thick) was placed horizontally on two support rods spaced 200 mm apart as indicated in Fig. 3b, the measurement system was positioned 3 mm above the plate. The hereby used cubic spline interpolation provides extrapolated points outside the matrix of measurement channels.

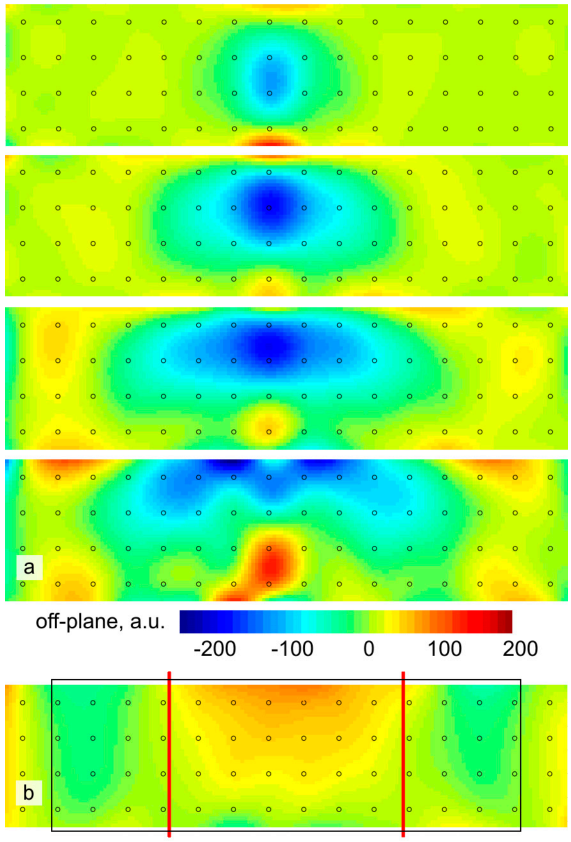

Fig. 3. (a) Data frames with interval 83 µs showing a wave propagating in a CFRP plate after a central hit. (b) A standing wave 85 ms later. Black rectangle indicates plate boundaries, red lines – support rods.

Fig. 3a reproduces every fourth frame of the data stream, giving an overview of the wave evolution during 250 µs after the excitation. The normal plate mode arising later is shown at 85 ms after the event (Fig. 3b).

As the next step the authors plan to perform a detailed comparison of the results with data of established vibration measurement methods.

References

[1] F. Riesberg, D. Felsl, S. Haase, N. Rümmler, Detektion von Strukturschäden in Faserverbundwerkstoffen mittels demontierbarer Sensorik, *Proc. Landshuter Symp. MST*, 147-154 (2016)

[2] H. Fleischer, Schwingungsuntersuchungen an der Violine. Beiträge zur Vibro- und Psychoakustik 1/10, UniBw und TU München (2010)

[3] J. Gomes, Y. Ishii, B. Ginn, Non-stationary Holography on Arbitrary Source Shapes, *Proc. Internoise* (2014)

[4] B. Forssen, M. J. Crocker, Estimation of acoustic velocity, surface velocity, and radiation efficiency by use of the two-microphone technique, *Journal of the Acoustical Society of America* 73, 1047 (1983); doi: 10.1121/1.389152