

Scan & Listen: a simple and fast method to find sources

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ABSTRACT

The particle velocity field close to a source almost matches the surface vibration whereas the sound pressure field is mainly caused by the background noise. Here a new method is proposed that is to simply listen to the particle velocity field to find sources. The method shows to give a very fast first impression of the acoustic problem at hand.

INTRODUCTION

Locating sound sources in a practical environment can be difficult. To have a quick scan instead of a long time taking series of measurements an intuitive method for source finding can be handy and is found in the 'Scan and Listen' method.

The novelty is that the acoustic particle velocity is made audible instead of the sound commonly known sound pressure. An evaluation of the sound pressure is not leading to results in acoustic difficult environments. The reason why is one of the topics of this paper. The method is demonstrated for some practical cases apart from that.

Acoustic sources that are most difficult to find are sound sources in a reverberant environment with extra other acoustic noise sources. Unfortunately this is the most common situation: sources have to be found inside a car, plane or similar surroundings where acoustic background noise is strongly present.

Especially in surroundings with a lot of background noise a quick diagnose is required as an alternative of e.g. holography or beamforming systems.

By good and skilful listening, one can locate the dominant sound sources easily.

THEORY

Suppose that there is a structure S that vibrates, and where external noise comes in due to leakages.

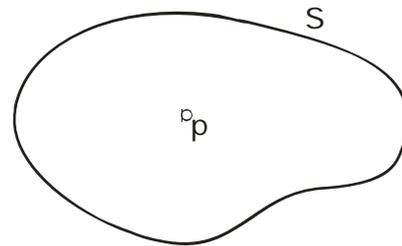


Figure 1: A closed surface S and a sound pressure measured at a certain location.

The sound pressure p , inside the structure is then given by the Helmholtz integral equation:

$$p(\vec{x}) = \oint_S \left\{ \frac{\partial G(r)}{\partial n_y} p(\vec{y}) + i\omega\rho G(r)v_{n_y}(\vec{y}) \right\} dS \quad (1)$$

If the (Greens-) function $G(r)$ is measured with a monopole at the position p and the pressure and velocity measurement (vehicle is not in operation) the equation can be rewritten so that [1]:

$$p = \iint_S \left[\frac{p_Q}{Q} u_n - \frac{u_{Q,n}}{Q} p \right] dS \quad (2)$$

with p_Q/Q is the transfer function from the monopole at the listeners position to the pressure at the surface and $u_{Q,n}/Q$ is transfer function from the monopole at the listeners position to the normal velocity at the surface.

Normally in a car (if the boundaries are reflective): $p_Q/Q \gg u_{Q,n}/Q$ and when the vehicle is in operation the surface velocity is larger than the surface pressure so: $u \gg p$. in such case the equation simplifies to:

$$p = \iint_S \frac{P_Q}{Q} u_n dS \quad (3)$$

Note: the scan and listen device has the possibility to switch to a pressure signal. This mode can be used to determine the path (p_Q/Q).

So the pressure at a certain location is only dependent to the velocity at the surface and the measured transfer function p_Q/Q . (and not in any way to the sound pressure at the surface).

Methods works best at rigid surfaces and lower frequencies (measurement distance is small compared to the wave length) [2].

In 'difficult' sound fields, e.g. diffuse sound fields or a situation with a lot of sound sources, it is a difficult task to find specific sound sources. In the near field of sources the use of a Microflown is advantageous over a pressure microphone because of three reasons [2], [3].

1. The sound pressure level and particle velocity level are of similar magnitude in the free field. If the sound wave reflects on a rigid surface, the sound pressure doubles and the particle velocity reduces to zero. Therefore the Microflown will not pick up much of the background noise. The sound pressure microphone will pick up this (doubled) noise:

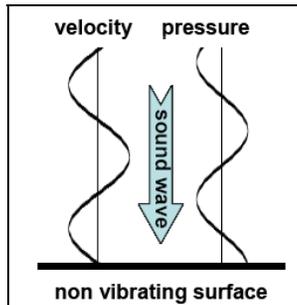


Figure 2: Background noise causes a high sound pressure and a low particle velocity level at a rigid surface.

2. Vice versa, close to a vibrating (sound emitting) surface, the sound pressure level is reduced compared to the particle velocity level perpendicular to the surface. Therefore the sound pressure microphone will pick up less signal level from the source than the Microflown:

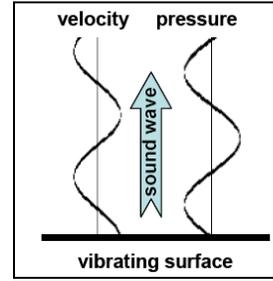


Figure 3: Close by a vibrating structure a high particle velocity level and a low sound pressure level is observed.

3. A sound pressure microphone is omni-directional and thus measures the sound field in all directions. A Microflown measures the particle velocity in one direction. Therefore when measuring in a diffuse sound field a Microflown measures only one third of the total sound field whereas a pressure microphone measures the total sound field [3]:

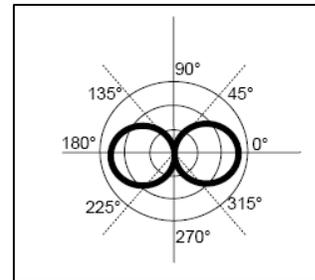


Figure 4: A particle velocity sensor is directional.

MEASUREMENTS

Several measurements are done to demonstrate the capabilities of the scan and listen method.

LITTLE HOLES AS SOUND SOURCES

A measurement scan over a little (1cm) opening in a rigid plate with a loudspeaker behind it with one particle velocity sensor pointed towards the plane of the source and one pressure sensor was done to illustrate the difference in performance for finding a source, see Figure 5, [4].

The measured auto spectrum of both sensors (microphone and Microflown) is taken for each place in the scan and in a bandwidth between 100Hz and 200Hz. The results of the measurements are shown in Figure 6 and Figure 7. As can be seen in Figure 6 the pressure sensor signal shows a clear peak in the response when near to the source. The particle velocity sensor has a more sharp peak, this is caused by the relative high particle velocity level and the directional behavior of the Microflown. Both methods are clearly useable.

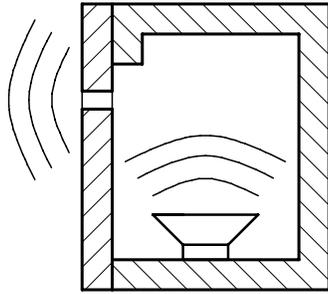


Figure 5: Sound emission from a small hole.

However in many cases background noise is present. So the scanning test is done again, but now with an external sound source generating background noise. Clearly the pressure signal now gives a blurred image in which the origin of the noise source can hardly be determined anymore. The particle velocity sensor however gives a comparable signal as without background noise see Figure 7.

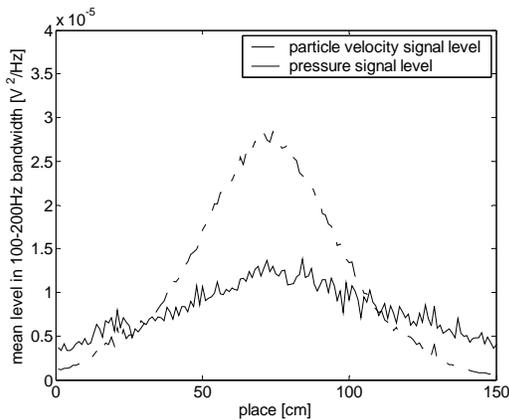


Figure 6: Surface scan without background noise.

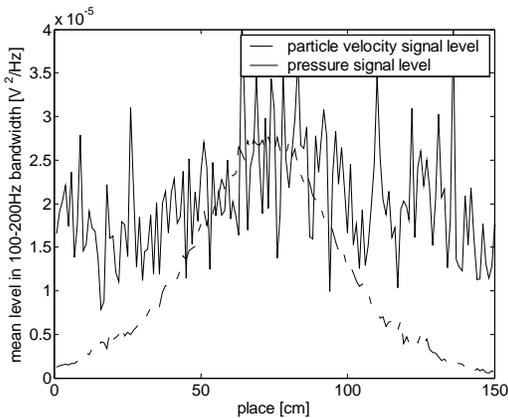


Figure 7: Surface scan with background noise.

EXPERT OPINION ON ADVANCE-IGNITION KNOCK

With the scan & listen method it is possible in an intuitive way to find sound sources. An expert can quickly find the sources he is interested in without the disturbance of background noise.

Advance-ignition knock and detonation during combustion can be easily detected. These measurements have been done in the laboratory of combustion engines of the HAN where experts detected these locations.



Figure 8: Measurements on a combustion engine.

WIND NOISE IN A LUXURY CAR

A research group of an undisclosed OEM has applied a scan and listen probe for the wind noise in a luxury car without noise cancelling headphone.

The car was positioned in an operational windtunnel and they listened to the output of the particle velocity probe by headphone while sitting inside the car and had actual feeling of wind noise direction and location.

The scan and listen method is used for the sound ranking and localization of wind noise related problems around the a-pillar.

SIMPLE METHOD FOR FINDING MODES IN A THIN PLATE

For a lab experiment the modes in a 33x43cm 0.8mm thin plate had to be found [5]. In Figure 9 the result of a simple method to visualize mode shapes is shown. The method employs one scan and listen probe. The normal velocity of the surface is scanned and the signal is amplified and made audible through headphones. The regions with zero vibration are easy to measure and are marked with a whiteboard marker in blue.

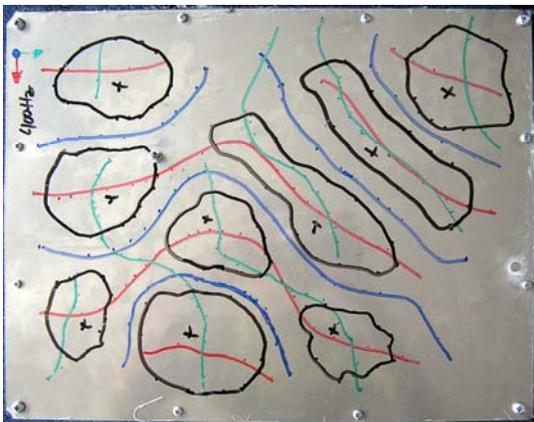


Figure 9: A simple way to find a modeshape at 400Hz. In red and green are the lines of zero lateral velocity shown. In black iso-velocity lines and in blue the lines of zero normal velocity. The black crosses are the points of maximal normal velocity.

Then the probe is moved away from the zero vibration lines and the position of a certain particle velocity level (that is read out with an analogue RMS meter) is marked. The Iso-vibration lines that are formed with this procedure are marked in black. In the middle of these regions the vibration level is measured and noted. The complete procedure takes five minutes for a 30x40cm plate for one single frequency.

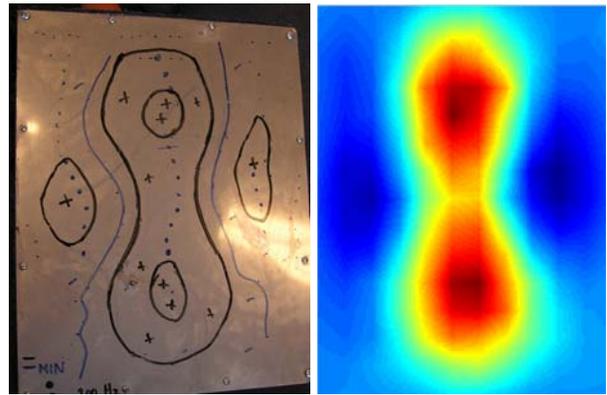


Figure 10: Modes measured at 200Hz with the simple whiteboard marker technique compared with a high resolution (180 points) surface velocity measurement.

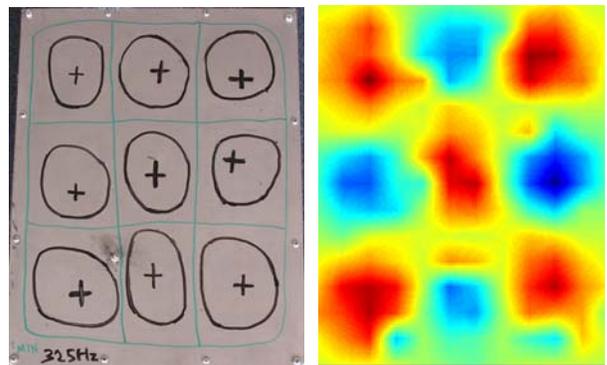


Figure 11: Modes measured at 325Hz with the simple whiteboard marker technique compared with a high resolution (180 points) surface velocity measurement.

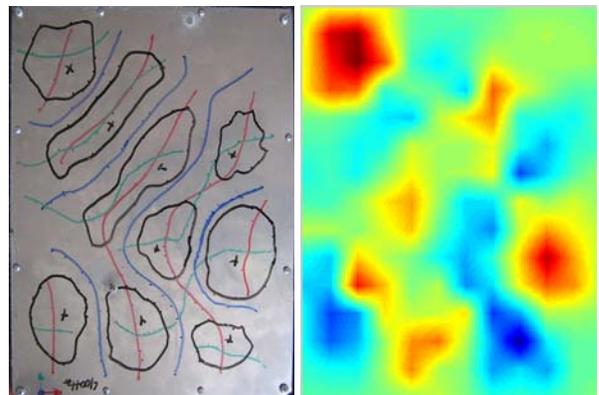


Figure 12: Modes measured at 400Hz with the simple whiteboard marker technique compared with a high resolution (180 points) surface velocity measurement.

In red and green the lines of zero lateral velocity is drawn in Figure 9. A crossing of those lines marks a maximal normal velocity. The ‘scan and listen’ method is compared with a very near field multipoint measurement (180 points). This measurement took about one hour. As can be seen the measurements coincide nicely.

In Figure 10, Figure 11 and Figure 12 left, the velocity profiles are determined with the scan and listen method. All of these profiles are made with a single sine wave excitation. In the right pictures white noise was applied and the velocity profile was made with a particle velocity based acoustic camera. The results match closely as can be seen.

The scan and listen method produces a fast result for a single frequency with a minimal use of equipment. After some setup time the particle velocity based acoustic camera produces broad banded information (so a lot of single frequency pictures at once). However the equipment requirement for this acoustic camera is substantial.

NON-STATIONARY SIGNALS LIKE TRANSIENTS

An apart group of acoustic problems is the finding of so called non-stationary sources. One can think of squeak and rattle problems, door slams etc.

In order to analyse a transient (impulse) type of acoustic signals two experiments have been done. The sound field of a gong is studied in the presence of a loudspeaker that generated white background noise. After this the gong was replaced by a miniature loudspeaker that generated low level impulses (one ‘click’ per second).

The gong experiment

In the gong experiment the difference between p and u can be heard clearly. If one is listening to p and u close to a gong plate without any background noise it sounds about similar. But if one listens to p and u close to the surface of a hard steel plate that is opposite of the gong (Figure 13) the sound pressure can be heard quite loud, but the particle velocity is almost faded out. This shows that close to a hard surface background noise is reduced considerably.

The sound pressure and particle velocity are measured again close to the surface of the gong, but now with background noise.

The background noise is dominant for the sound pressure measurement close to the gong. But when the particle velocity is measured the background noise is reduced so that the sound of the gong is the most dominant source.

If p and u are measured again close to the surface of a hard steel plate that is opposite of the gong the background noise is only heard when sound pressure is measured and almost no noise (neither background noise nor gong noise) is heard when particle velocity is listened to.



Figure 13: Gong measurement setup.

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In this experiment it was noted that it was possible to hear the gong in the sound pressure signal when the loudspeaker was generating background noise. Also a human could hear the gong in the presence of the noise. This is because sound of the gong has a complete other nature than the white noise. Although it was possible to hear the gong in the sound pressure signal in the noise, it was not possible to locate it: at the steel plate opposing the going the perceived sound pressure was similar as close to the gong. With sound pressure signal it is not possible to locate the gong, independent of the noise source was switched on or off.

For the particle velocity signal it is completely different story. With the loudspeaker generating white noise at the position of the gong the gong signal is most dominant and at the steel plate opposing the gong, the

levels were low. In this example it is simple to find the location of the gong.

Clicking sound in the presence of background noise

A miniature loudspeaker was generating one click per second. The sound was just noticeable when the background noise was switched off.

A miniature loudspeaker was generating one click per second. The sound was just noticeable by human hearing when the background noise was switched off if the white noise source was switched on the clicking could not be distinguished. With a particle velocity probe it was easily possible to detect the non-stationary click while listening with the pressure microphone the perceived sound was overwhelmed and dominated by the background noise. With the (particle velocity) scan and listen method it was simple to localize the sound source.

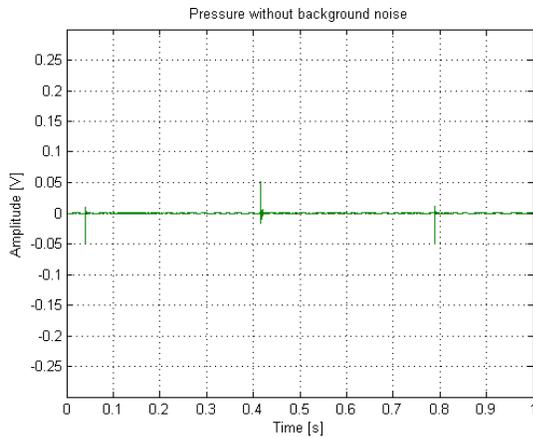


Figure 14: Sound pressure measured close by the miniature loudspeaker (no background noise).

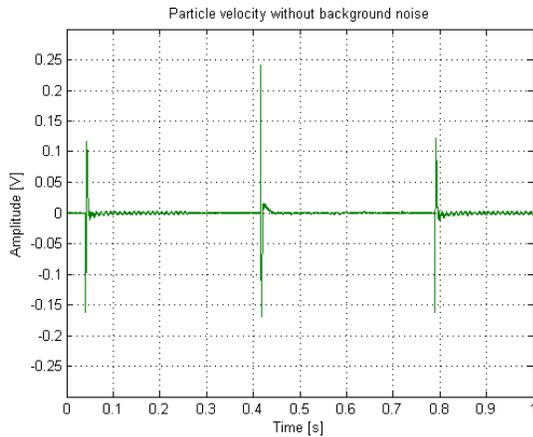


Figure 15: Particle velocity measured close by the miniature loudspeaker (no background noise).

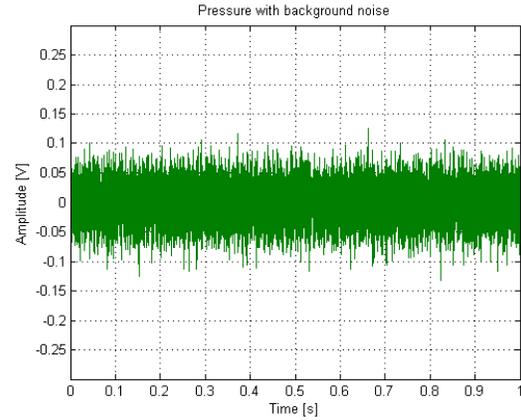


Figure 16: Sound pressure measured close by the miniature loudspeaker (with background noise).

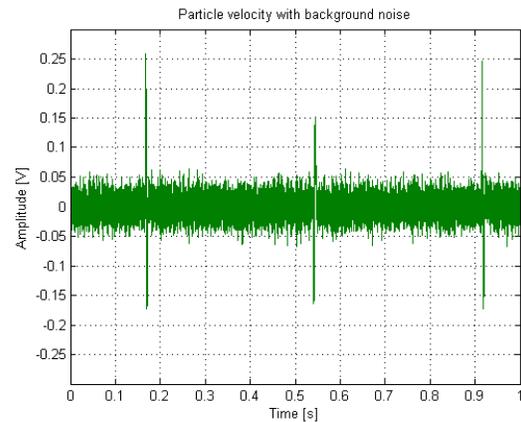


Figure 17: Particle velocity measured close by the miniature loudspeaker (with background noise).

As can be seen in Figure 14 to Figure 17, the sound pressure level close to the source is lower than the particle velocity level. Of course particle velocity and sound pressure cannot be compared directly but if one is observing the effect of the background noise one could say that the effect is (regarding level) somewhat similar. The measured particle velocity level (see Figure 17) is somewhat smaller than the measured sound pressure level (see Figure 16).

The clicking noise (the pulse shaped signal) cannot be found in the pressure signal with background noise and can clearly be detected in the particle velocity signal.

END OF LINE CONTROL

The method can be extended to an end of line (or in line) control. Some products have a specific noise level target. Usually the requirement is defined as a test in an

anechoic room where a certain sound pressure limit specifies the maximum allowed sound emission.

It is clear that the test in an anechoic room cannot be done in the production line. Other sensors like push-on accelerometers or laser vibrometers are commonly used in such cases. The particle velocity sensor is a third option.

The scan and listen method delivers a fast assessment if the particle velocity sensor can be applied as an end of line sensor.

A set of good and faulty (half) products are scanned and the most distinguishing points (regarding good/faulty) on the surface. Once these points are known the products are tested in the production line to find out if faulty products can be detected in the presence of (machine)vibrations and the background noise of the production hall.

If the faulty products can be found by simply listening, a software solution is developed to automate the procedure.

CONCLUSIONS AND RECOMMENDATIONS

In this paper a particle velocity based method is presented that is based on scanning a surface whilst listening to the particle velocity signal. The method proves to be simple to use and (non stationary) sources can be found in complex sound fields like a car interior.

Theory based on the Helmholtz integral equation is presented on why it makes sense to observe the particle velocity instead of sound pressure and several examples are presented.

Here a gong, a small loudspeaker clicking and noise from a small hole in the presence of background noise is investigated. Advanced-ignition knock on a combustion

engine is assessed by an expert. Mode shapes are visualized on a thin plate.

The method shows to be a powerful tool in testing environments where the location of annoying sources need to be found quickly.

Quick, fast and mobile. Its mobility is practical, simple and handheld.

Scan and listen can be used for a first feasibility study in an end-of-line control problem.

Although the method shows to have practical benefits, some drawbacks have to be listed. The sensor seems to distort in the presence of wind (windshields may avoid this). It is not possible to distinguish if sources are coherent and no phase difference can be observed in visualization of modeshapes.

It is not possible to make pictures as one can make with the acoustic camera or a holography system

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