Scan&Paint, a new fast tool for sound source localization and quantification of machinery in reverberant conditions

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Abstract

Sound source localization methods are widely used to reduce the sound emission of machinery. These methods are based on sound pressure measurements and often require an anechoic environment to be applied.

The Microflown sensor can measure particle velocity directly which is less affected by background noise and reflections. This property of the sensor is now used together with a new approach termed *Scan&Paint* for fast stationary sound source localization.

Introduction

In this paper a relatively new Scan&Paint method [1], [2] is presented that uses only one probe that is sensitive for both sound pressure and particle velocity. The probe is swept close to the surface and at the same time the audio data is measured also video is captured. With software the probe position is recognized from the video frames in the screen and at that position the sound field is represented. Because the sound probe captures both sound pressure and particle velocity it is possible to measure the particle velocity field and the sound intensity field directly.

The method is fast (low set up time and low acquisition time), it does not require much training to be able to work with the system, it is broad banded (20Hz-20kHz), the influence of reflections or extraneous noise is low and it is low cost compared to other source localization methods.

The traditional source localization methods can be divided in two groups: near field methods and far field methods. The most common method near field method is holography. Usually the particle velocity distribution at the surface is calculated from of the measured sound pressure distribution. Disadvantages of the method are the need of a large array of microphones that has to be positioned close to the surface of the sound radiating object which requires quite some set up time. Also the equipment costs are high, the method requires quite some education, results are sometimes not accurate, and the method works in a limited bandwidth.

The most common far field localisation techniques are beamforming methods where an array of microphones is placed far from the source. The array of spaced microphones act as a highly directional microphone and the source distribution can be measured relatively easily. The method requires less set up time than holography and requires less some education. However the equipment costs still high, the results are not always accurate due to reflections etc., the absolute source strength cannot be obtained and the method works for higher frequencies (depending on the microphone spacing).

Because of the operational bandwidth of the above mentioned methods it is common to use one array of microphones and hardware for the beamforming and holography. These methods require restrictions of the acoustic environments. Because both sound pressure based holography and beamforming cannot distinguish the direction of propagation of the sound field one needs to take care that only the object under test is radiating sound and that there is other sound sources or reflections have a low level.

Sound fields

The noise problems can be divided in two groups: stationary problems and non stationary problems. Examples of stationary problems are turbulent flow noise and noise generated by a machine with a constant RPM. Non stationary problems occur with engine run ups etc.

The Scan & Paint method cannot be used for non stationary problems. However because the methods is fast and straight forward, it is sometimes possible to make the problem stationary by fixing the RPM, measure, and alter the RPM again.

For complex non-stationary measurements like engine run ups of e.g. turbo's charged engines and driving the car on the road, scanning methods cannot be used: the sound field is time dependent and should therefore be measured at each place at the same time.

It is also important to know if sources are coherent. In this context coherence means that the sound pressure at a specific location (or the sound radiation) depends on the phase of (other) sources.

Stationary and non-coherent noise problems can be visualized by simply stitching local results. This is because the phase of the local sound field is of no importance and the statistical properties of the sound field are constant in time. Examples of such events are e.g. wind tunnel measurements at frequencies higher than 500Hz for normal passenger cars. (Usually noise sources are non coherent at higher frequencies). For the visualization of such noise problems the Scan & Paint method can be used.

For lower frequencies sources may be coherent and the phase of the sources must be taken into account. Stationary and coherent noise problems are common at lower frequencies. In such cases the phase of the surface particle velocity must be known. It is possible to use a reference sensor for this. The method on how to deal with coherent noise sources is dealed with in this paper.

Acoustic environment

Measurements in enclosed non anechoic environments (like inside a car, train, plane, building, machine shops, etc.) and measurements with extraneous noise sources that cannot be shut off are usually very difficult to handle with traditional measurement methods. This is because beamforming and holography (and traditional pp intensity methods) are sensitive for extraneous noise. The direct measurement of particle velocity makes it possible to measure in these common acoustic environments with a high level of background noise [3], [4].

In the near field of a sound source (at low frequencies) almost all energy is kinetic energy (velocity). With pu probes the velocity from the surface is directly and easily measured. This is proven in many studies; see e.g. [5], [6], [7], [8], [9], [10], [11], [12].

Velocity is much less affected by background noise than pressure because:

- The impedance of many surfaces is high, and close to such reflecting objects the sound pressure due to the background noise will increase (~6dB), while the velocity measures almost no background noise. At the surface, most potential energy (pressure) and kinetic energy (velocity) will be converted to potential energy, because the surface itself will not move due to external noise sources.
- In the acoustic near field there is a high particle velocity level compared to sound pressure due to the vibration of the surface itself.
- The directivity pattern of the sensor: the velocity sensor has a figure-of-eight sensitivity, whereas sound pressure transducers are omni-directional. This means external sources from other directions are not measured.

It is not always possible to use the velocity method at high frequencies if the probe-surface distance is large (near field conditions are not met anymore). The intensity can be used instead. Compared to pp intensity probes, pu intensity probes are small and have no spacing problem, but more importantly pu probes can be used in environments with high levels of reflections or background noise (no p/I index problems), [13], [14], [15], [16].

General description of the measurements

To demonstrate the Scan&Paint method several test objects are measured. The time required for the individual measurements varied from 1 to roughly 6 minutes. The scaling of the colormaps is in dB and a velocity reference value of $5e^{-8}$ m/s (velocity) and $1e^{-12}W/m^2$ (intensity) are used.

Example I: Emitted sound of a kitchen blender

The emitted sound of a blender is determined by scanning the surface. The probe position is captured and recognized automatically by the software. The path of the probe is shown by the green dots in Figure 1 left. The broad banded noise emission is shown in Figure 1 right.

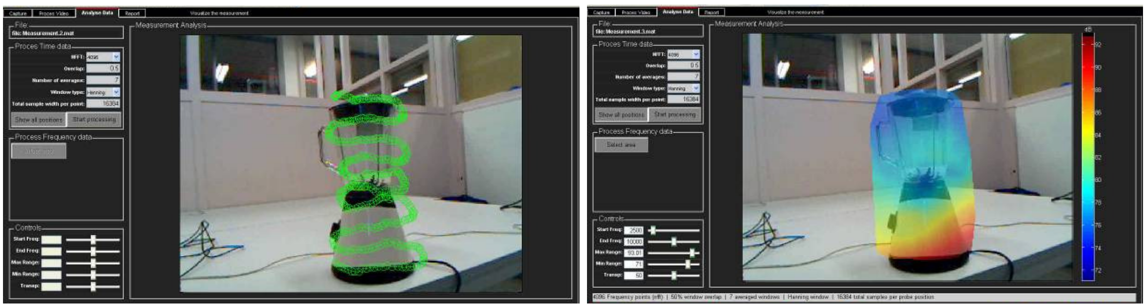

Fig. 1: Left: Path of the probe derived from the video frames. Right: broad band velocity.

The total measuring plus processing time was in the order of three minutes.

Example II: Emitted sound field of a vacuum cleaner (wind noise)

The emitted sound field of a vacuum cleaner is measured in a regular office with the Scan&Paint method. A complicating factor is the exhaust flow of air. A special windcap is used to protect the probe from the airflow and to capture the emitted sound field.

In Figure 2 (left), the captured sound field is shown as time format in the screen below (red and blue plot). With this feature the sound field can be listened to for checking the signal and get an understanding of the sound quality.

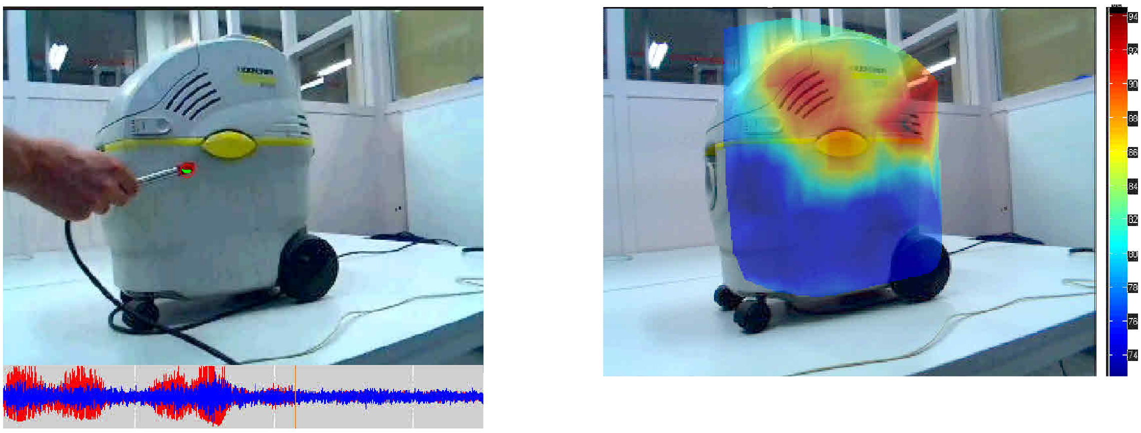

Fig. 2: Left: The surface of the vacuum cleaner is scanned with the intensity probe. Right: the emitted sound field.

The total measurement plus processing time was approximately of three minutes.

Example III: Emitted sound inside an airbus aeroplane (interior noise)

Interior noise problems are usually very complex. This is because the sound field in an interior has a very high pressure-intensity index (because of the many sources and their reflections the sound pressure is high compared to the sound intensity). With a traditional p-p sound intensity probe it is difficult to measure, while the pu method can be used.

The surface is scanned inside the plane, see Figure 3 left. Right the emitted sound field is shown.

Fig. 3: Left: The surface of an aircraft luggage compartment. Right: Velocity (10-1000Hz).

The total measuring plus processing time was in the order of ten minutes.

Example IV: Emitted sound inside a train.

In the previous example the sound field was measured in a test set up, so without passengers. In this example the emitted sound field of a window was measured during a train trip with regular passengers. The measurement was not noticed in a way that caused discomfort. The video was captured with the webcam of a laptop and the surface scan took a few minutes. The sound emission of the window was measured but to our surprise the sound emission of the window was much less than the emission of the window frame, figure 4.

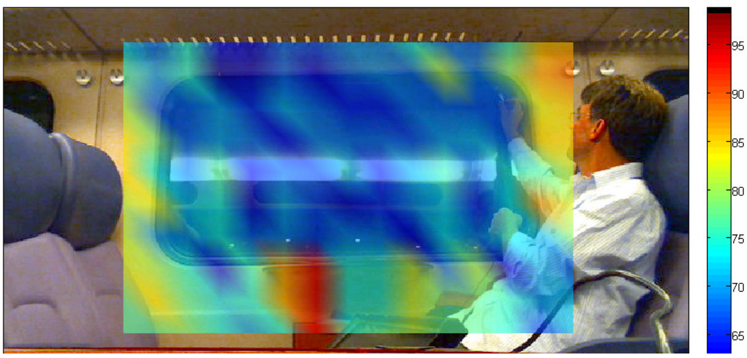

Fig. 4: Velocity distribution of a window in a normal passenger train (60-1650Hz)

The total measuring plus processing time was in the order of three minutes.

Example V: Emitted sound inside a car

The front part of a car interior has been measured. The velocity colormap is somewhat influenced by the slight breeze of the ventilators (right fan and at the bottom of the windscreen) because no wind cap was used, figure 5.

Fig. 5: Velocity distribution inside a car (400Hz)

The intensity measurement is affected less by the wind turbulence than the velocity measurement because the intensity is calculated from the cross-spectrum of pressure and velocity. Because the wind noise is highly uncorrelated much of the influence is reduced. Also the influence of wind on the velocity sensor is less at higher frequencies.

To show it is possible to locate broad band sound sources inside a car, three loudspeakers are positioned on the dashboard and measured, figure 6 (The level of the middle speaker was slightly higher). Interestingly even the round contours of the speaker membrane seem to be visible, while the surface scan was done relatively quickly (~1.5 minutes).

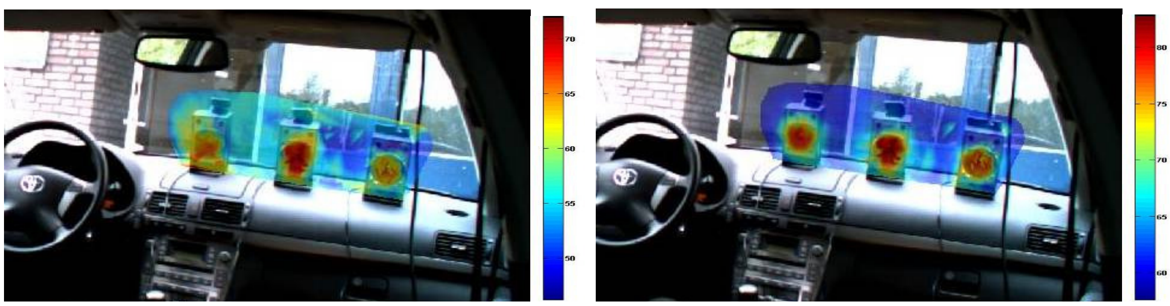

Fig. 6: Colour map of three speakers (white noise input). Left: 55-143hz. Right: 800-1500Hz

Also measurements with the Scan & Paint method have been made in a car driving on the road, but unfortunately there was no approval yet from the customer to disclose the data and therefore the results could not be used for this paper.

Example VI: Scanning Transfer Path Analysis

A more advanced application of Scan&Paint is Scanning Transfer Path Analysis. Two measurements are performed in this application. Firstly, the transfer path from the source surface to the listeners ear is measured. This is achieved reciprocally, by placing a loudspeaker at the lister's position and measuring the pressure at the surface. Secondly the particle velocity is measured at the surface and a reference sensor at the listener's ear is used to determine the phase. The product of the source velocity and the transfer function at a given point the contribution of that point to the pressure at the listener's ear.

Figure 7(left) depicts the autospectrum of the surface velocity. Figure 7(right) depicts the contribution of each point to the sound heard at the listener's ear (the velocity, multiplied by the transfer path). In this figure, it can be seen that the loudspeakers have opposite phase.

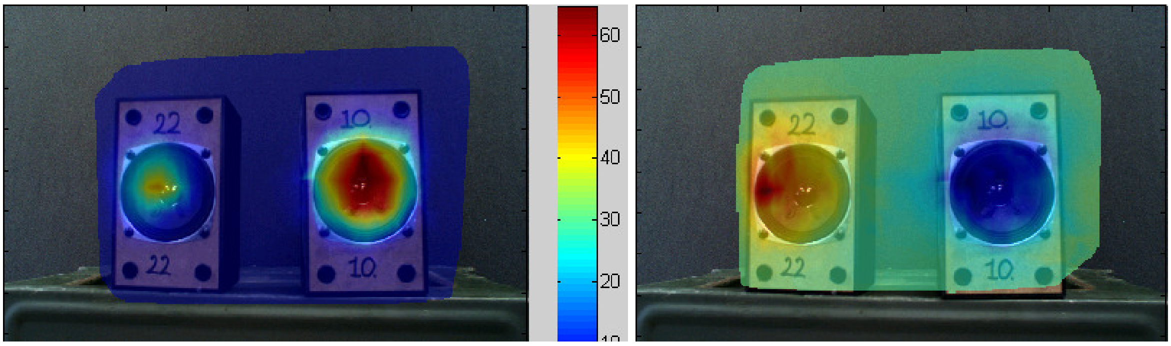

Fig. 7: Colour map of two speakers that are driven in anti phase. Left shows the velocity autospectrum (no phase information); Right shows contribution of each point to the pressure at the listener's ear.

Conclusion

The Scan&Paint method makes it possible to localize stationary sources in its operating condition, within a few minutes. A simple scan of the surface is recorded by a video camera and synchronized with the audio data. The position of the probe can be recognized by the video and the colour map can be calculated in very high resolution.

The Microflown probe allows different kind of machinery to be measured even in reverberant condition or in presence with strong background noise using the intensity or velocity measurement. Some examples are shown to demonstrate the validity of the method.

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