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AN INTUITIVE HANDHELD ACOUSTIC NOISE SOURCE FINDER

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ABSTRACT - An apparatus has been developed to find acoustic sound sources in the near field of a radiating object operating in a noisy environment. It is based on two orthogonally placed particle velocity probes (two Microflowns[1], [2]). The complete signal processing is done in real time with battery powered analogue circuitry, resulting in a very small and handheld measurement device. One Microflown is used to display the sound level and to listen to the source whilst rejecting the background noise and another Microflown is used to create a stereo indication in which direction the device must be moved to pinpoint the noise source.

TECHNICAL PAPER - In complex sound fields, e.g. diffuse sound fields, reflections or many simultaneous radiating sound sources, it is often a difficult task to find specific sound sources with pressure microphones. However, in the near field of sources the use of a Microflown is advantageous over a pressure microphone because of three reasons [3]:

1. The sound pressure level and particle velocity level are of similar magnitude in the free field. Close to an acoustic hard surface, the sound pressure doubles and the particle velocity reduces to zero. Therefore, when a particle velocity sensor such as the Microflown is held close to a hard surface it will not pick up much of the background noise. The sound pressure microphone will pick up this (doubled) noise.
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.
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 diffuse background sound field whereas a pressure microphone measures the total sound field [3].

The intuitive handheld Acoustic Noise Source Finder (ANSF) consists of two Microflowns placed orthogonally to each other. Microflown A aims in the forward direction and Microflown two is placed orthogonally so that the sensitivity is zero in the forward direction. See the photograph in figure 1 for a graphical representation of this. On top of a printed circuit board a black piece of silicon with two elevated blocks can be seen, wires are placed between these blocks, and for this element the sensitivity direction is in line with the printed circuit board (S1). The other element is placed on the other side and has sensitivity directions of S2.

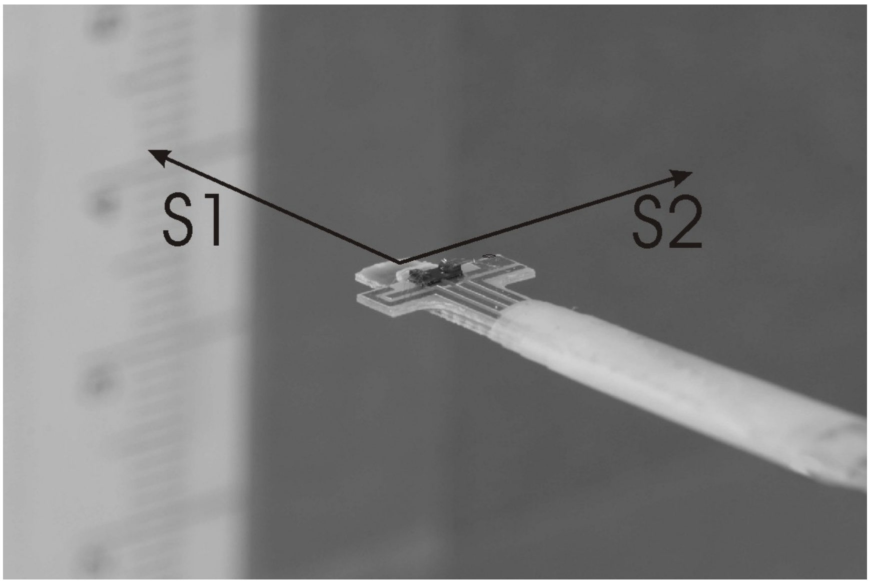

Figure 1; Photo of the sensor device

The signal of Microflown A (S1) is amplified and connected to headphones. Because of the three effects that are mentioned before, this Microflown has the benefit of rejecting the background noise and amplifying the source signal.
So with this Microflown one is already able to find sound sources in a better way than with pressure microphones. The source is located at the position where the sound is at its loudest level. Although it is possible to find sound sources with only one Microflown, a second, perpendicular placed Microflown is added.
With the use of the second Microflown it is possible to generate a signal that indicates direction of particle velocity. With some additional electronics there is now a possibility to send directivity information to the ears of the user. Once the two Microflowns are moved over the sound source, the source signal distributed between the headphones left and right channel so that the source can be located easier. The subject of this paper is the design of the handheld device.

SOUND SOURCE LOCALIZATION - When a particle velocity signal is present with a component in the plane of sensitivity of the two microflown sensors the signals can be used to determine the direction and magnitude of that particle velocity signal.
Assume that the particle velocity signal is a pure sine signal. When multiplying both signals with each other there will be a resulting signal of

$$Us = \frac{1}{2} A \sin(2\alpha) \sin^2(\omega t)$$

With A the amplitude of the signal, ω the angular frequency and α the angle of incidence. Depending on the value of α the sign of *Us* will change. The time average of this signal divided by the amplitude A of the particle velocity signal (extractable from sensor A and B) gives a direct measure of the angle of incidence of the particle velocity direction and level. The signal *Us* can be used together with the signal obtained from microflown sensor A to locate the source of an acoustic noise source when connected to an indicator displaying the average voltage.
Following the measurement procedure is in short explained. The apparatus is held in hand and turned on. The frequency filters are adjusted in such a way that the annoying sound to be located

is heard clearly trough the headphone in an as small as possible bandwidth. When the source of the noise is on the left side of the sensors the voltmeter showing the average multiplied signal shows a negative voltage (meter is turned to the left), and vice versa when the noise source is on the right side. When the source is exactly in front of the sensor the meter will show “zero”, or “straight ahead”. Together with this voltmeter two variable gain amplifiers are steered in such a way that the user experiences the noise going from left to right when moving the noise source finder from right to left. This assists the process of finding the noise source. The source finding technique is similar to that used with intensity probes

IMPLEMENTATION - Implementation of the signal processing described above can be done with analog or digital electronics. Digital processing requires a computer, which is large, or a dedicated DSP, which is relatively complex. Since the processing is relatively easy, an analog processing circuit has been applied for this prototype. Schematically the electronics used can be described as shown in figure 2.
The signal of Microflown A is amplified, band pass filtered and fed to a headphone section with AC voltmeter. Band pass filters are needed because of two reasons. Firstly they enable the user to focus on a specific noise source, and secondly they are needed to get a useful signal from multiplying the signals. When e.g. multiplying 1/f (pink) noise signals with a specific bandwidth the lower frequencies in that bandwidth will be largely responsible for the output level. If the bandwidth is not too large this effect is less present.

In principle it is now already possible to find an acoustic hot spot in a certain frequency band. The use of headphones facilitates location finding of specific noises. When the audio signal is at its loudest one has found the acoustic hot spot. Advantage of the filtering is that one can localize a specific (band pass filtered) sound while more noise sources are present.
The signal of Microflown two is also band pass filtered and then multiplied with the band pass filtered signal of microflown A. The resulting signal is averaged. This results in a signal that is zero if the sensors are located exactly in front of the hot spot, a negative DC signal when the sensor is on the right of the hot spot and a positive DC signal when the sensor is on the left of the hot spot. This signal is fed into a voltmeter which can be used for indicating where to move the ANSF in order to locate the hot spot. The multiplied and integrated signal is also used to operate two voltage controlled amplifiers feeding the audio signal to the headphones. The panning of the audio between left and right is controlled by the DC signal. When the hot spot is on the left side of the ANSF the left headphone signal is louder and vice versa. Only when the hot spot is in front of the ANSF the signal is equal on both headphone channels.
Amplifiers A1 and A2 can be replaced by voltage controlled amplifiers as well; the amplification must then be controlled by the output of the filters in such a way that the output level at the filters is kept more or less constant. This improves the working of the system in terms of a larger dynamic range and a more truthful response of the magnitude of the direction signal, which is now less dependent on distance. Optionally there is a microflown correction circuit; this is implemented to correct the microflown frequency response in terms of a high frequency amplification to enhance audio fidelity.

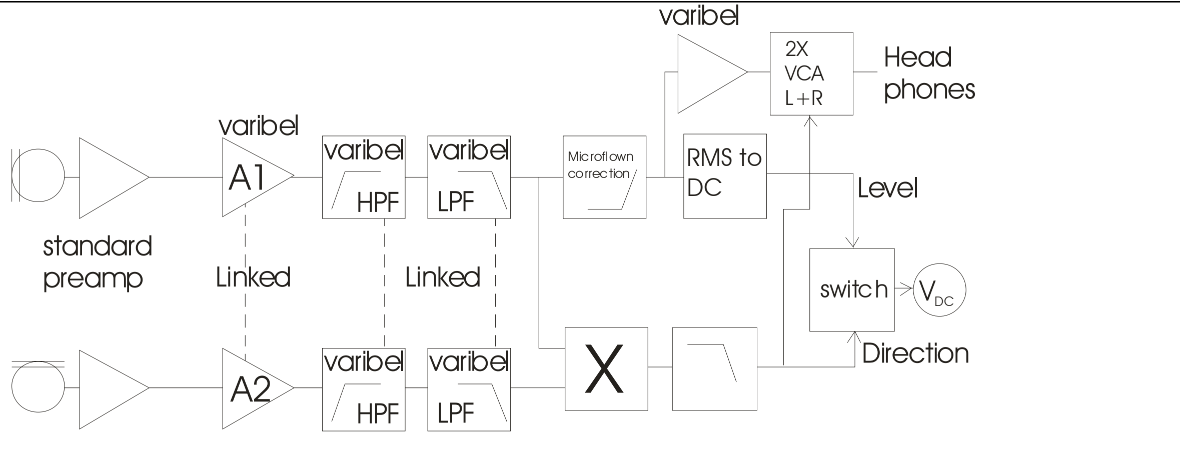

Figure 2, schematic representation of electronics

MEASUREMENTS - Next a series of measurements are done, starting with the Intuitive Acoustic Noise Source Finder or ANSF. Use is made from an automated traverse robot to ensure exact positioning of the device and reproducibility of the measurements. Firstly the ANSF is tested in a quiet environment with only one source nearby the sensor. Next a comparing measurement between the use of pressure sensors and particle velocity sensors when measuring near a sound source is done. Dependent on the outcome of these measurements the measurements with the ANSF are continued, but now with background noise present.

MEASUREMENTS WITH THE ANSF - Since the system is designed for use with both vision and hearing the output can not directly be used in this paper. Instead of using the system the way it is designed measurements are done using the direction signal and the band pass filtered signal from sensor S1.
The two microflown sensors are placed at a distance of 2.5cm from a plate with a sound source in it. Then a scan is made in a plane parallel to the plane with the source, see figure 1, the plate can be seen fuzzy in the back. The source consists of a loudspeaker behind a hole with diameter of 2cm and is excitated with white noise. In the case of these measurements a band pass filter is chosen with a pass band from 100 Hz to 1 kHz, which is a very wide frequency band and a more difficult test for the system than when a small band is used. A scan with 15 points in the horizontal direction and 9 points in the vertical direction is made, each point has distance of one centimeter between neighboring points. Firstly with the sensitivity axis of sensor two (S2 in figure 1) in the horizontal direction and secondly in the vertical-direction. The resulting output signals of the scan with sensitivity in the horizontal direction are plotted in figure 3a. As can be seen the amplitude of the signal is maximal when approaching the source, and changing sign when crossing the source. The same measurement is performed with microflown two's sensitivity axis parallel with the vertical axis. Results of these measurements are shown in figure 3b, a similarity with figure 3a clearly exists except for that the figure is 90 degrees rotated when seen from above. Since measurements are done in the whole plane at a fixed distance both in the horizontal and vertical direction, this creates the possibility to display a vector plot of the measurements. This vector plot can be seen in figure 4a. Clearly the arrows point towards the point source; however at larger distances the arrows are too small to recognize a direction. Therefore the same graph is printed in figure 4b, but with a logarithmic scale of the values. At the

edges the values do not point towards the source anymore, so there the noise level is too high. The sensor pointing to the plane with the source has barely signal strength because the component in this direction is very small; this is the explanation why the averaged multiplied signal does not point in the right direction. At 6 cm distance the vector plot is much smoother and values all over the whole grid point toward the source, the signal is now much more constant over the scanning surface. See figure 5 for the 2-D vector plot of this data.

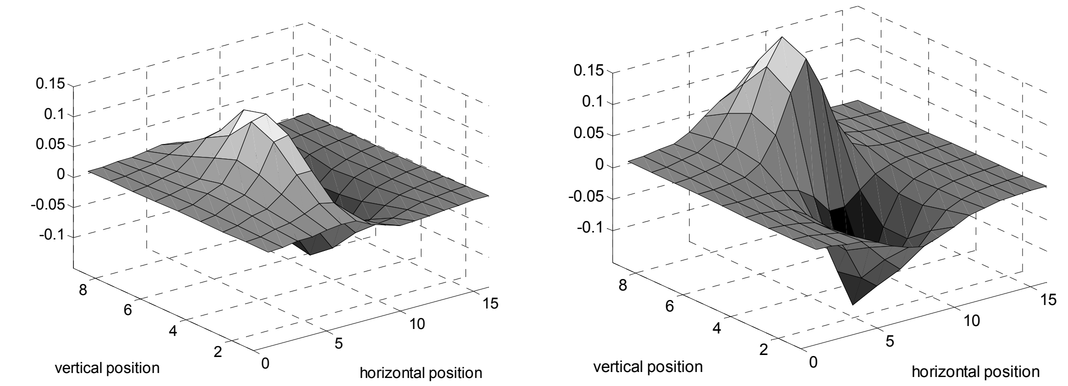

Figure 3 a and b; measurement results of scanning a point source and plotting the averaged multiplied signal source. Figure 3a with horizontal sensitivity direction, figure 3b with vertical sensitivity direction

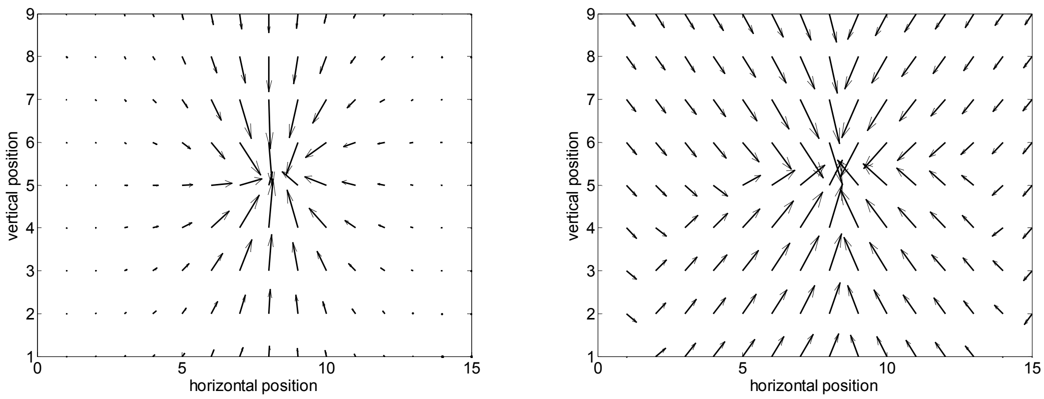

Figure 4a and b; vector plot of measurements at 2.5 cm distance. In figure 4b the values plotted are taken as (1/log(data)) for readability.

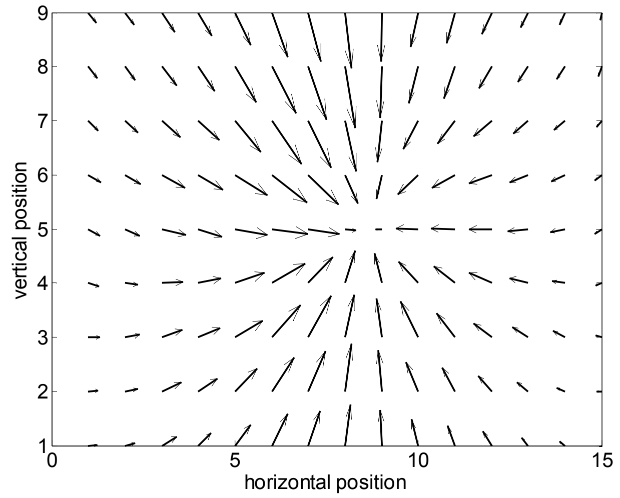

Figure 5; vector plot at 6cm distance

COMPARISON BETWEEN PRESSURE AND PARTICLE VELOCITY SIGNALS - To illustrate the difference in performance between using a pressure microphone or a particle velocity sensor for scanning a source a comparing test near a source is done. A measurement scan over the source with one particle velocity sensor pointed towards the plane of the source and one pressure sensor is done. The measured auto spectrum of both sensors is taken for each place in the scan and in a bandwidth between 100 Hz and 200 Hz the logarithm of the data points is taken and all data is summed and scaled. The results of the measurements are shown in figure 6. As can be seen 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, which originates to the directive nature of the particle velocity sensor. Both methods are clearly useable. However in much cases background noise is present. So the scanning test is done again, but now with an external sound source generating background noise. The background noise level is set so that when a pressure microphone is positioned 5 cm away from the sound source in the plate the background noise results in more pressure signal than the source in the plate produces. Clearly the pressure signal now gives at best a very rough indication about the location of the sound source, whereas the microflown signal is gives a comparable to the situation without background noise. See figure 7.

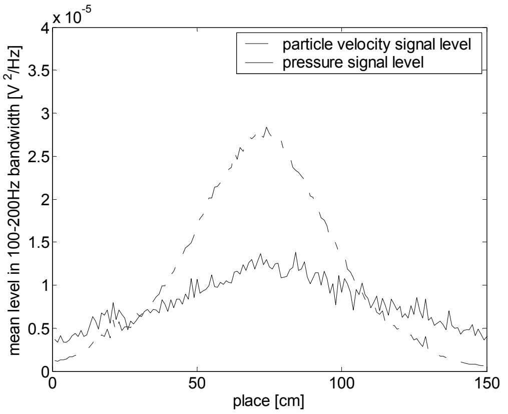

Figure 6; scan without background noise

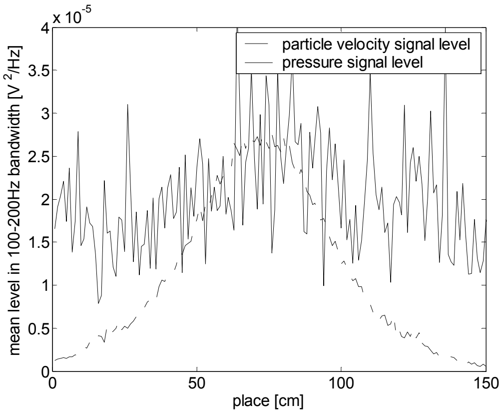

figure 7; scan with background noise

MEASUREMENTS WITH THE ANSF AND BACKGROUND NOISE - Another scan with the two sensor system is performed, this time with 5cm distance to the plane with the source and background noise present. The level of background noise is equal to the level used with the test described above. Together with direction signal (the averaged multiplied signal) the amplitude of the signal from sensor A, pointing towards the plane, is monitored. This time the filters are adjusted to a smaller bandwidth. To evaluate the frequency response of the filters a frequency response of one channel of the system is shown in figure 8; this describes that the filter is set to a relatively narrow pass band of 150Hz to 225Hz. In figure 9 both values are plotted against the traveled distance. Values are scaled to a good fit, since absolute values are not of importance here. The source can be found at the maximum of the amplitude of the signal from sensor one and the changing of the sign of the direction signal. Here the use of the direction signal comes to its right; with help of the output signal of sensor A the source can be found globally, but the direction signal gives the exact point.
The results that are depicted in figure 9 are measured in the presence of background noise. From the previous results it was shown (see figure 6 and figure 7) that the Microflown in the normal direction S1 is not affected by background noise. A Microflown in the lateral direction however is affected more by background noise because the lateral component of the background noise does not reflect on the surface. However because the lateral velocity is multiplied with the normal velocity and averaged, the effect of the background noise is averaged to zero.

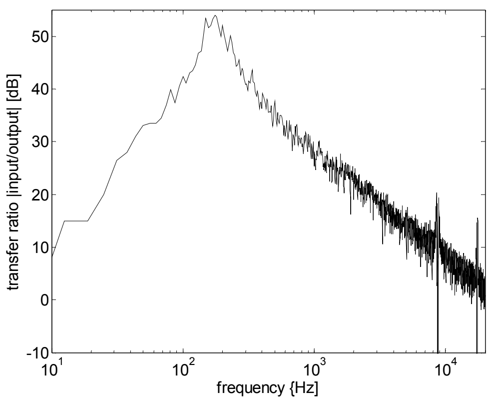

figure 8, measured response of one channel.

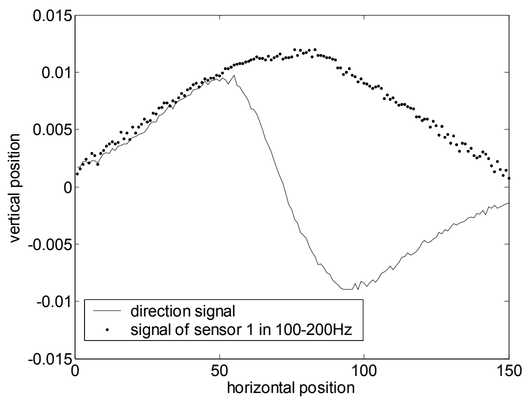

Figure 9; Measurement at 5 cm distance and background noise present.

CONCLUSIONS - An intuitive acoustic noise source finder for use in an environment with background noise is presented. A direction indicator pointing towards the source enables the user to find a noise source quickly and intuitively. It is proven that background noise has less influence on the measurements when measuring particle velocity than when measuring with pressure microphones. An addition on the electronics in the form of an automated gain control system is a possible improvement to enhance the dynamic range and possibly the working distance.

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