Introduction to a new 3-dimensional method to visualize sound directivity based on a moving microphone array and beamforming

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ABSTRACT

The aim of all sound visualization methods is to show the acoustic behaviour of the object in test as precise as possible. Most accurate results can be reached with methods taking all directions of sound emittance into account. These 3-dimensional methods require either a high number of microphones or moving the sensors around the object and a 3D model of the object itself. This work will introduce a new method based on moving a microphone array around the test-object to gather information from all directions. Furthermore, a 3D model is automatically generated with an integrated 3D point scanner. The introduced method also allows to get and visualize information about the directivity of the emitted sound. The underlying fundamental principles and the theoretical background will be explained. Results of some example measurement will be presented and the limitations and possibilities of the method will be discussed.

1. INTRODUCTION

As a first step in many fields of acoustic analysis it is of great importance to exactly know where sound is coming from. There are different methods to get that information and since a few years acoustic imaging methods are applied. The most commonly used is beamforming. This microphone array-based method is taking the runtime delays of the different microphone channels into account for differentiating between areas of a sound emission and of no sound emission. Since the first commercial systems where launched they have been constantly improved. There is a high number of algorithms to decrease the spatial resolution and increase the dynamic, algorithms to erase unwanted

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sound sources, to be able to localize tonal sources or to analyse coherences. They all have in common to get better and more precise results.

Since a few years it is also possible to do 3D beamforming – analysing the test objects from all sides and mapping on a 3D model. This method has the clear advantage of getting information from different directions to cover the full radiation pattern of any test object. Besides that, the result is not based on a single focus-distance between microphone array and test object, but on several distances between microphone array and 3D points or meshes.

The normal procedure to get information from all directions is to adapt the microphone arrays. Either several arrays are combined or a designated array measuring all directions is designed. (Figure 1 and 2). Both ways usually imply an increase of channels hence increasing the costs.

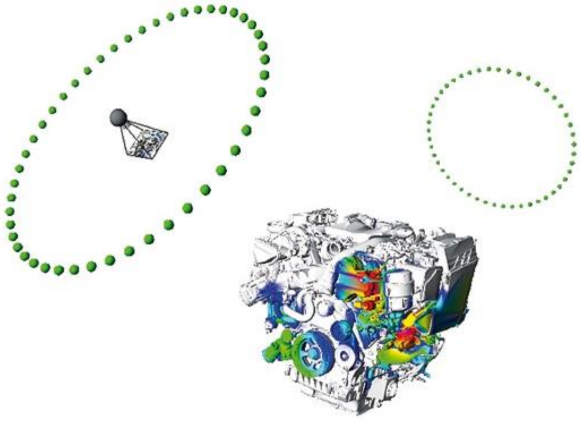

Figure 1: Engine on test stand, two ring arrays and merged acoustic maps

Figure 2: Half dome array

To get the correct focus information beamforming 2.5D was introduced recently [1]. This method is based on a microphone array connected to a depth camera (Figure 3. optical camera with infrared projector and camera) instead of a standard optical camera. With this set-up it is possible to get the distance information to different objects automatically based on the spatial information generated by the depth camera. The result is a 2D image combined with the 3D information and thus called 2.5D.

Figure 3: Intel RealSense depth camera D435 (source: https://www.intelrealsense.com/depth-camera-d435/)

Adding the depth camera to the microphone array offers the potential to combine the advantages of 3D beamforming without increasing the number of channels. This patented method is called dynamic beamforming and has been introduced recently. Figure 4 shows a 96-channel handheld acoustic camera system with integrated RealSense depth camera.

Figure 4: Acoustic camera system with integrated 3D depth camera (source: https://www.acoustic-camera.com/en/products/microphone-arrays/mikado.html)

2. DYNAMIC BEAMFORMING

The basic idea of dynamic beamforming is to get as much advantage as possible of the additional information from the depth camera to increase the result of the beamforming image. This includes:

- Generating a 3D model of the test object
- Automatically fitting the position of the microphone array to the 3D model
- Measuring the test object from all sides
- Information about sound directivity and radiation characteristics
- Minimize side-lobes
- Information about sound power values

2.1. Depth Camera

Since a few years there has been a rapid progress in small and inexpensive 3D cameras. The Intel RealSense D435, which is implemented for this set-up, works with stereo cameras, a Full HD RGB camera and structured IR light. It generates so called depth images, a standard 2D image (x, y) with z-information about the depth for each pixel. Moving the camera around an object several depth images are generated from different positions. Each image has a certain offset to the previous image and combining this information allows to generate a 3D model of the scene. The resolution of the model is around 5mm, which is a reasonable accuracy for mapping the sound distribution and directivity on it. Figure 5 shows the resulting 3D model of measuring a vacuum cleaner. The grey dots show the trajectory of the moved scanner.

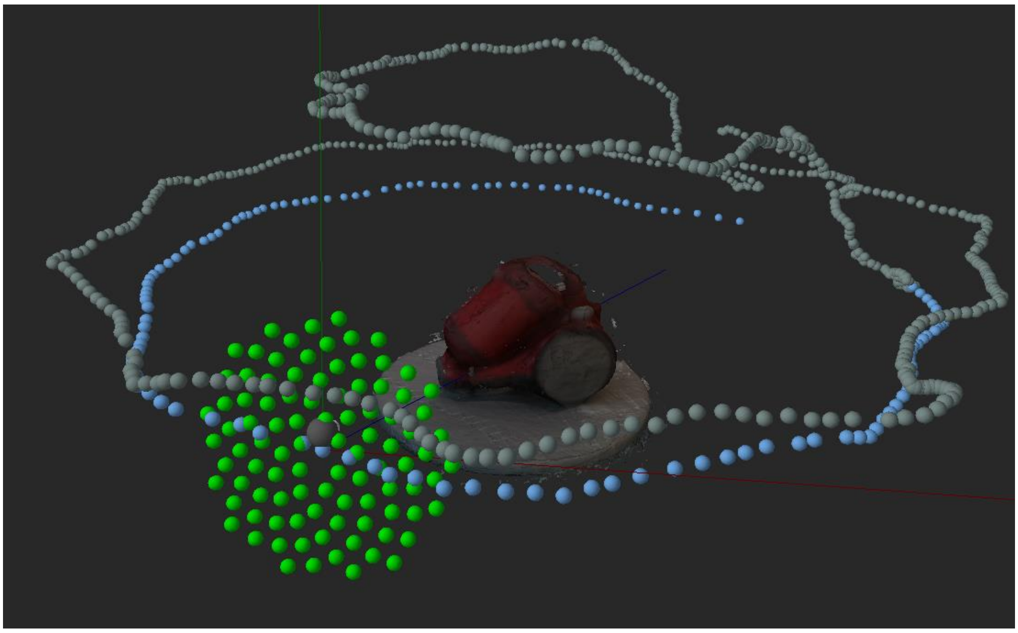

Figure 5: Scan-positions (pale blue points), recording position (grey points) and 3D model of the test object.

2.2. Fitting of the 3D model

For 3D beamforming it is of great importance to forward the exact position of the microphone array in relation to the test object to the software. Usually there are dedicated fitting algorithms where the user can take the optical information of the microphone array's camera and position it in the correct relation to the 3D model manually. With dynamic beamforming it is not necessary to apply any additional algorithm. The depth camera is directly connected to the microphone array and the relative position of the microphones to the object / 3D model of the object is transferred while recording the audio data. The blue points in figure 5 show the measurement positions of the array. As the system not only records the relative position for one measurement point but also takes the full trajectory of the array into account this technique offers new possibilities to analyze the sound propagation.

2.3. Measuring the object from all sides

To conduct a measurement with dynamic beamforming, the microphone array with connected depth camera is moved around the test object in an arbitrary trajectory. All directions should be covered to record the complete sound propagation. A preview in the software shows the already recorded 3D model and the current position of the 3D camera / microphone array. For each measurement point in the trajectory of the movement an acoustic map is generated for the meshes of the 3D model. The calculation is based on known beamforming methods. The acoustic maps of all measurement points are summed up and get weighted subsequently.

2.4. Sound directivity

Measuring the object from different sides and all directions allows to get information about the radiation characteristics of the identified sound sources. This information can be visualized e.g. by indicating the directivity with animated arrows. Fig. 6 shows the result of a measurement of the vacuum cleaner in this case of the 3150 Hz 3rd octave band.

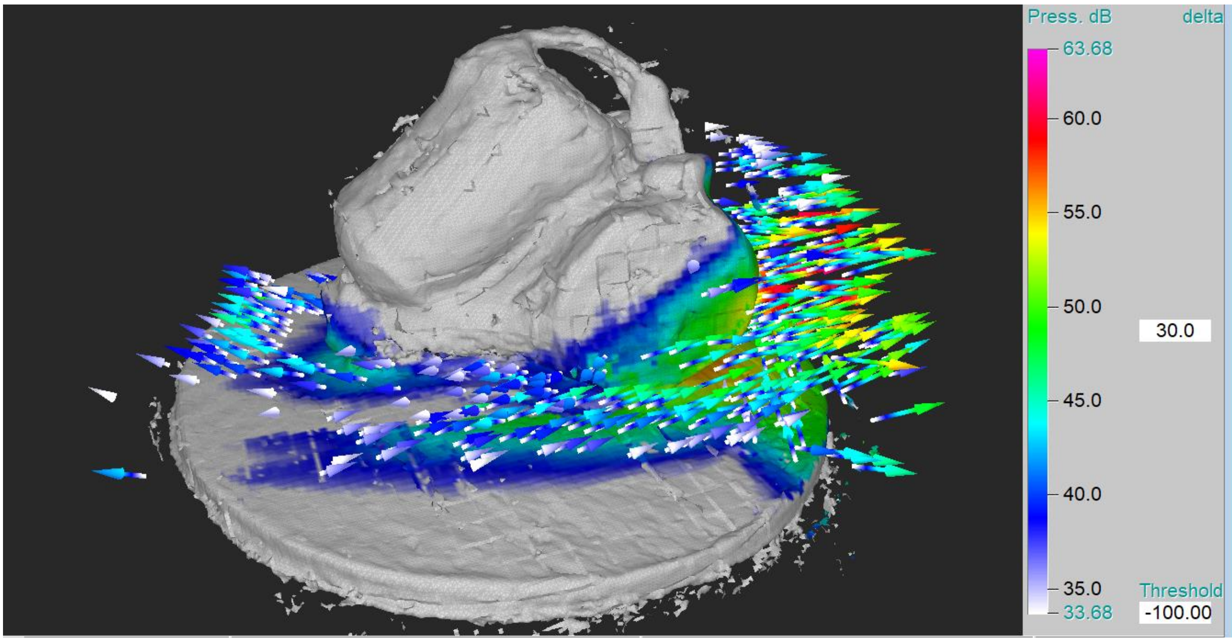

Figure 6: 3150 Hz 3rd octave band with directional information indicated by arrows

2.5. Increase of result quality

The introduced method not only has advantages in the area of 3D beamforming, it can also be applied for 2D analysis. Every array geometry has certain limitations especially related to so called side-lobes, which are patterns usually not related to a sound source but to the distribution of the microphones. Summing up the measurements of all positions will increase the result quality for 2D analysis, as the algorithms can differentiate between side-lobes and actual sound sources for each position. The sound sources will stay at the same spot whereas the side-lobe patterns will move with the measurement position. Figure 7 shows the result of the measurement of a mobile phone, the left image shows the result without optimization and the right side shows the merged map. It is clearly visible that the side-lobe patterns close to the actual source are erased.

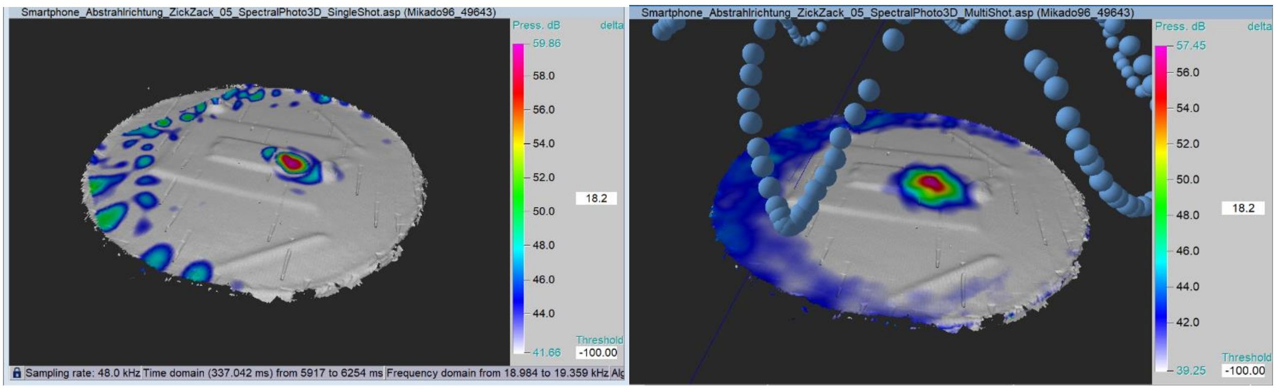

Figure 7: 2D beamforming, from one direction (left), merged image (right)

2.6. Sound power values

By measuring a more or less enveloping area around the sound source it is also possible to evaluate the sound power values of the object. As the beamforming techniques also offer precise information about the single sources the sound power information of certain sources can also be determined.

3. MEASUREMENT EXAMPLES

Several test measurements have already been conducted to prove the functionality of this approach. Figures 8-9 show results of the measurement of a speaker and of a smartphone emitting noise. The directivity can clearly be visualized depending on the frequency under investigation.

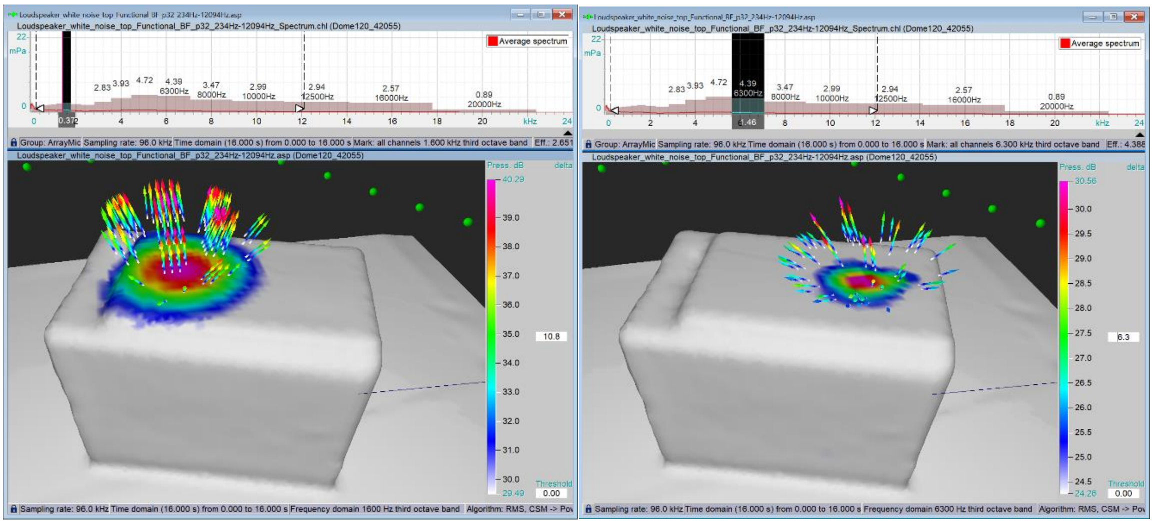

Figure 8: Directivity of a speaker, 1600 Hz 3rd octave band (left), 6300 Hz 3rd octave band (right)

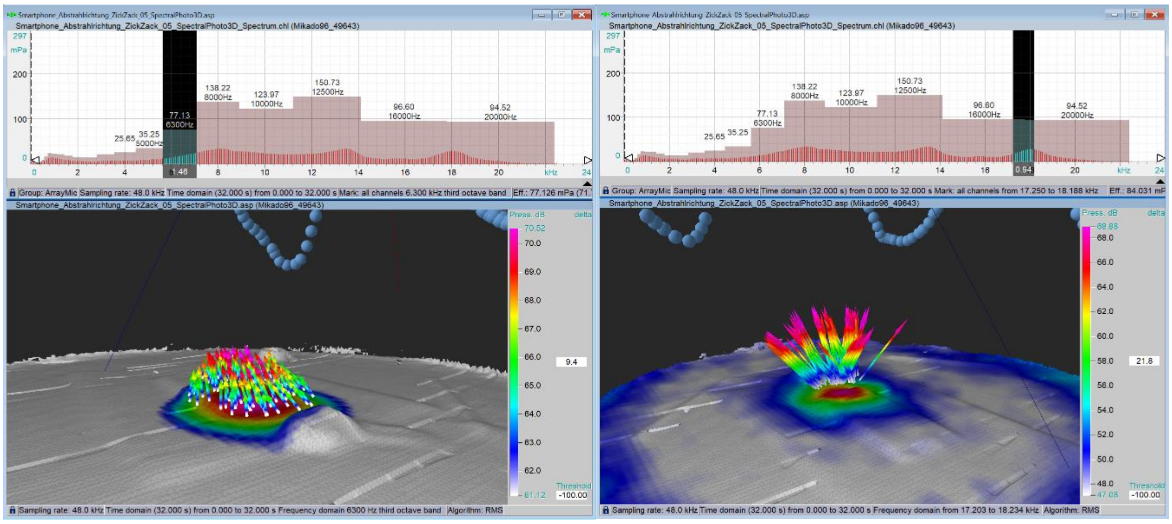

Figure 9: Directivity of a smart phone, 6300 Hz 3rd octave band (left), 17,2-18,2 kHz (right)

4. SUMMARY AND OUTLOOK

The introduced method combines a microphone array with a 3D scanner. A 3D model is generated and a measurement is conducted by moving the microphone array around the test object. The position of the array in relation to the object is tracked and information of each measurement position is taken into account for the analysis. The introduced so called “dynamic beamforming” has proven to be a valid method to optimize acoustic imaging results and to get more information about the sound emission of the test object. There is no need of an external 3D model and it is not necessary to apply any fitting algorithm manually. Information of the overall sound emission is gathered and can be visualized. Results for 2D beamforming analysis are optimized by suppressing the side-lobes of the single acoustic maps. In future it will be possible to get information about the emitted sound power of the whole object or of individual sound sources, which will be the aim for further research.

5. REFERENCES

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