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Dynamic beamforming using moving phased arrays with integrated 3D scanners.

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ABSTRACT

Throughout the past 25 years Sound Source Localization was a matter of two dimensional sound maps and acoustic images. Since 2001 Beamforming is also used inside a cavity such as cars and trains. Results are mapped onto given CAD models created by the 3D designers. The visualization of the sound sources was finally moving to the third dimension. Very often a 3D model of the measurement object is required, but not at hand. Including a 3D scanning device into a microphone array is consequential step that seems logical, but has been an extremely costly matter. When looking at the size of scanning data even its handling is a challenging issue until today, but computers get faster by the year and the real-time reconstruction of a 3D model of a measurement object is now a feasible approach. This paper presents a technique that shows the integration of a 3D scanning device into a microphone array to measure an object. This new way of using a microphone array with a 3D scanner allows a user to create a 3D model of a measurement scene and record and map the entire sound field instantly. Furthermore by moving the array around a measurement object one gets a much higher spatial sampling for the sound field and therefore much better understanding of the objects acoustic behavior. The aim of this paper is to present the first results of this approach and discuss its chances and challenges.

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1. INTRODUCTION

Microphone arrays – so-called Acoustic Cameras – come in many different forms depending on application. The base method that has been used, is Delay-and-Sum-Beamforming.

This technique is well known and Acoustic Cameras have been providing reliable results for many years. Heilmann, Boeck and Doebler (1) provide details on limits and expectation of sound source localization using beamforming. Comprehensive research on array design has been carried out by Schulze, Sarradj and Zeibig (2) and Sarradj (3). Acoustic Cameras have a huge field of applications and they are well documented in literature (see, e.g., (4–6) for recent work). Calculation methods and algorithms are constantly evolving. Additional work to building upon these methods can be found in Refs. (7) and (8).

The beamforming method has plenty of advantages over commonly used single microphone techniques. But when using Acoustic Cameras many new expectations may arise and one is confronted with the side lobe effects and limitations of dynamic and resolution. All these are always in direct relation of number of microphones and array shape to be optimized. Therefore most of the common scientific efforts aim to increase the precision and dynamic of the technology. Theoretically one would like to use an infinite number of microphones spread over an infinite space to cover the entire sound field. At places where there is no microphone every effort to reconstruct the field synthetically will never compare to an actual measurement, no matter how well the algorithm.

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This is called spatial under sampling. Figure 1 illustrates the effect of using more microphones in direct comparison. The measurement on the right, using 120 microphones shows far less side lobe effects in the same dynamic range.

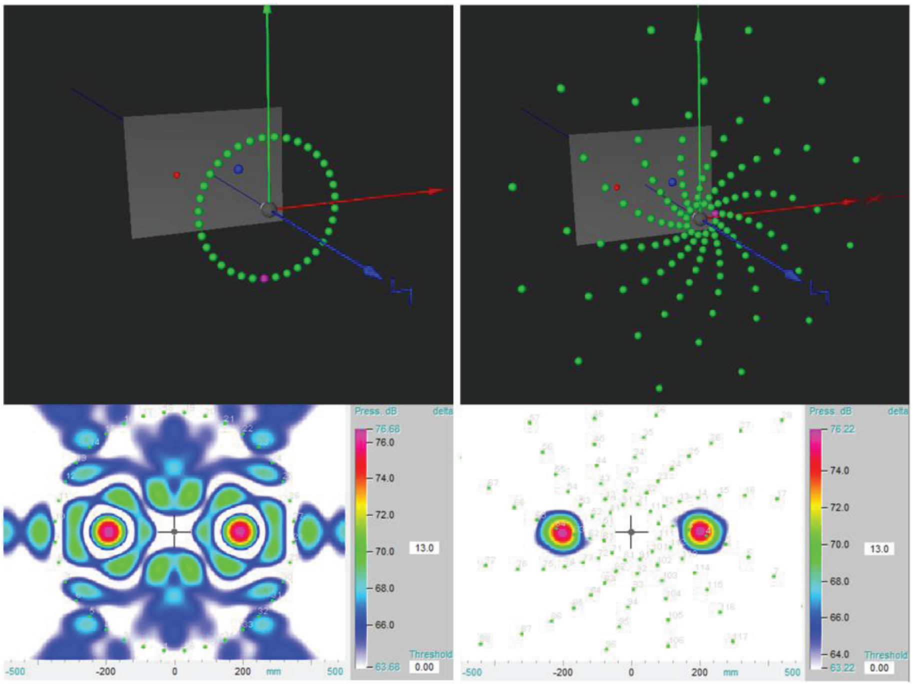

Figure 1 – left: two sources measured with 48 microphones and right 120 microphones

For most two dimensional applications this seems reasonable and provides results within acceptable accuracy. As soon as the measurement object shows some structural depth standard concepts seem to fail since most microphone array shapes are very sensitive to focal distance (12).

Solving this problem of depth of field the latest developments in 3D Beamforming also bring new challenges considering measurement technique and the signal processing (1,9,10, 13,16). 3D Beamforming can be performed with spherical arrays in cavities as shown many times before. The second approach uses multiple arrays around a measurement object (Fig. 2) or dome arrays (Fig. 3)

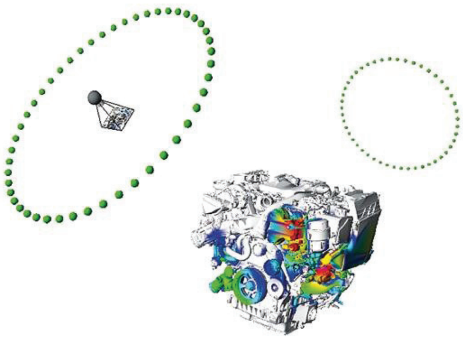

Figure 2 – Multi array measurement

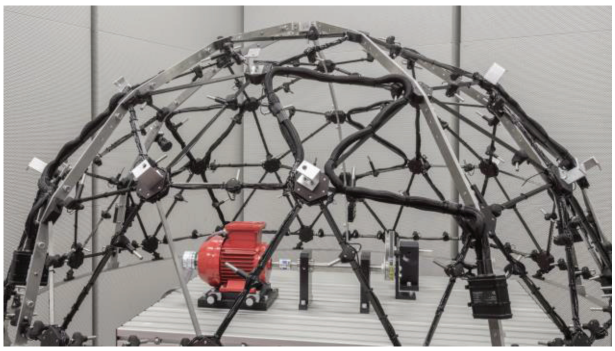

Figure 3 Microphone dome with 120 microphones

However, there are two additional problems of 3D-beamforming. Firstly, getting a suitable 3D-model and the determination of the coordinates and secondly the orientation of the array in relation to the 3D-model. A solution for the fitting problem was suggested in (9).

For many applications the source directivity as well as the source power plays an important role. Both of these values cannot be determined effectively with conventional techniques of the spatial under sampling of the stationary arrays (Fig. 2).

2. Dynamic beamforming using arrays with integrated 3D scanners

The Idea

The proposed approach of dynamic beamforming using phased arrays with integrated 3D scanners eases the essential problem of spatial under sampling by measuring at many different positions around a measurement object over a given time.

In all commonly used 3D phased array application both sound source and microphone array are considered to be fixed to each other. By introducing a scanner into the array we allow today one of the two to move relative to the other, because the spatial position can be tracked. When the array is moving around an object a complete 3D scan of the object can be obtained. Both a 3D object and a trajectory of the moving array is created while the acoustic information is recorded simultaneously. Using the trajectory, the position and the orientation of the array relatively to the measuring object is determined for each tracking point. The second option is a moving object in front of the microphone that can be tracked in the three dimensional space. A true dynamic 3D acoustic movie comes in reach.

To do so one has to overcome several challenges. The selection of right hardware is the first one. Today's acoustic market can't afford even more expensive measurement equipment. The first requirement of the introduction of such scanners for microphone arrays should not double the price of the entire sound source localization system.

3. Choice of hardware

3.1 Choice of scanners

Today's market for scanning devises offers a great choice of affordable hardware. Figure 4 shows a few of the available small and inexpensive scanners. To be implemented in a hand held microphone array the scanning device should be running on Windows, should be relatively small, lightweight and inexpensive. It should contain a video camera and a 3D scanner in one device with a sufficient resolution for both. During our test phase in 2014 - 2017 we investigated several different scanners (Figure 4). To name a few: Asus xtion, Structure IO, Kinect 1, Kinect 2 (TOF) have been tested extensively.

Figure 4 - shows a few of the available scanners.

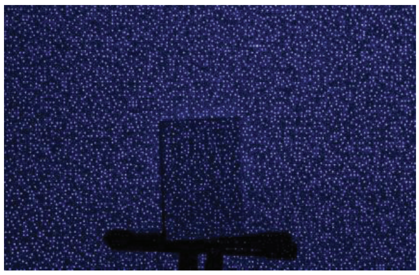
Figure 5 – structured light, scanning pattern

The first three of these scanners use a similar method of creating a three dimensional point cloud. A structured infrared light pattern is projected into the room and filmed by the infrared camera (320x240 pixel up to 640x480 pixel at 30 frames per second. The software of the scanners then calculates the depth information for each point by using the differences between the beamed and received picture. By moving the scanner around the object, a 3D point cloud is created. The software fits the three dimensional points to one 3D-Object and calculates the trajectory of the movement.

3.2 Combining microphone array and scanner

For our first setups we used a relatively small microphone array that can also be used as a hand held. The Ring32-35 is very lightweight and seemed the best choice for our tests. For the initial test the scanner was attached over the existing video camera.

Just attaching a scanner to an array of course is not giving you a 3D acoustic image or video. To record the scanning data and the microphone data we implemented a few changes into our software NoiseImage were needed. Implementing the scanner into the software we are using an existing software package that stitches the frames together in order to create a 3D object. For this we tested various different available SDK's. In our opinion the closed candidates where: ReconstructMe, Kinect Fusion (Microsoft) and Point cloud library (Source code, Cross compiling).

During an acoustic measurement the scanner and the microphone continuously feed data to our software NoiseImage. The sound is recorded as usual with microphone array data is stored into our *.chl file format as time history. The scanner is attached to our array and is set into the given 3D coordinate system assumed for the given microphones in the array. After the measurement, the software calculates the 3D-model and the trajectory of the microphone array and stores both into one file.

To create an acoustic image, one needs to calculate for every trajectory point (taken in 33ms intervals) a) the relation of the surface points of the object in relation to each microphone position and b) decide if it should be a part of the beamforming calculation. If a microphone is not in line of sight with a surface point it will be neglected for this calculation point and time. This is performed for every point and microphone at all measurement time intervals and builds the basis for the beamforming calculation. In order to test this workflow we created two different scenarios (Fig. 6). The first is a fixed path on a track for a reproducible setup. After the concept worked for this we allowed for a free hand movement of the array.

Figure 6 – Test setup including the array with a Asus XTION scanner

4. Results

The following part shows results using the Asus XTION scanner. Figure 8 displays a sequence of 4 selected point clouds which basically act as video frames with a resolution of 640x480 but with additional depth information using free hand path. So a 3D point cloud will be obtained during a movement around an object.

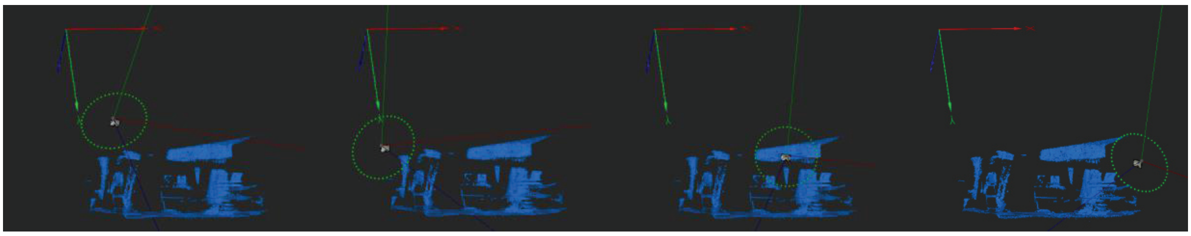

Figure 7 – Point cloud samples with relative array position

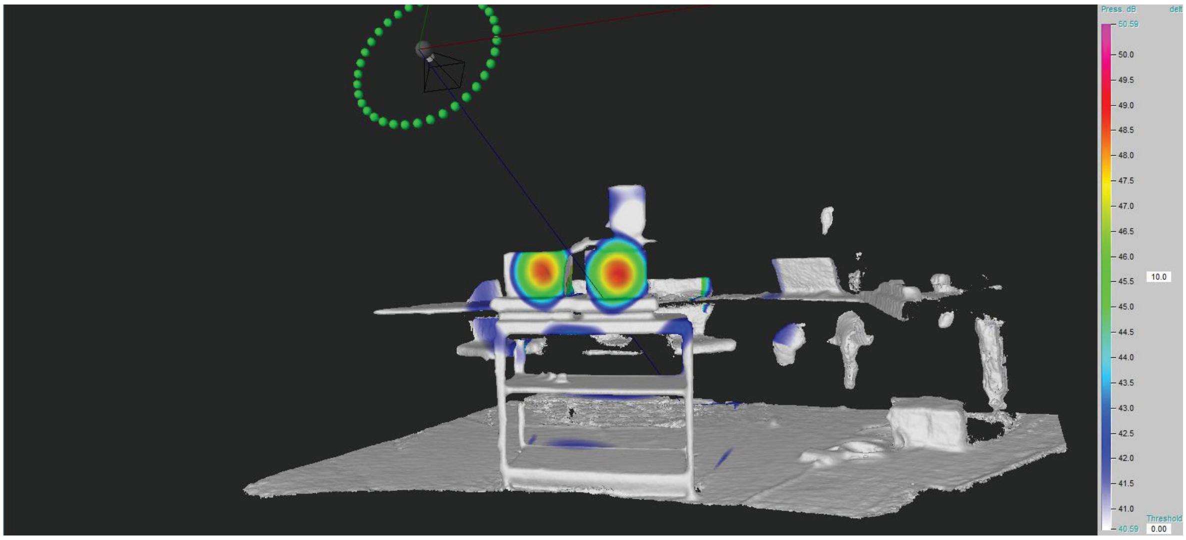

Figure 8 – Combining the meshed 3D scanning results and the acoustic image results

Meshing all of these scans will lead to a solid 3D object (Figure 8) the acoustic data is mapped on during a second calculation. Combining the meshed 3D scanning results and the acoustic image results provides extremely convenient results in a fast manner. The latest implementation shows a mobile hand held 96 channel MEMS microphone array system with an implemented 3D scanner.


Figure 9 – Acoustic Camera Mikado with 96 digital MEMS microphones with Structure Sensor 3D scanner.

5. CONCLUSIONS

Introducing a 3D scanning device into a microphone array allows to understand the entire sound field surrounding a measurement object. During a single scan around an engine or house hold appliance many acoustic measurement points will be available to calculate an exceptionally detailed 3D acoustic image with much more dynamic and resolution. Of course, this technique is limited to use for stationary or quasi stationary sound sources. In addition to standard beamforming results one can also reconstruct the source directivity of a sound source and also the sound power of the entire object or parts.

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