NOISE SOURCE LOCALIZATION WITHIN A CAR INTERIOR USING 3D-MICROPHONE ARRAYS

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ABSTRACT

The „Acoustic Camera“ is a measurement tool which joined the field of acoustics a few years ago also in industrial applications. Simple mapping of a virtual plane at a fixed distance is sufficient if the interesting object has a planar surface and we can arrange array and surface orthogonally. In contrast, the surface of many real objects shows complex three dimensional structures. In these cases, the approximation of three dimensional structures onto a plane implements errors in calculating the focus of the beamformer. A correct calculation is possible if we replace the mapping of a virtual plane at a fixed distance by different measurement distances to individual points at a 3D-model surface. The paper discusses advantages and disadvantages of 2D- and 3D-mapping.
In interior spaces the mapping of a plane is not practicable. A car interior for example is composed by many different flat and round subareas. In addition to mapping of three dimensional surfaces we need an omni-directional, non-planar array for complete 3D-mapping. A second problem is how to determine the position and direction of an array in the interior room. The paper discusses the geometry and acoustic properties of microphone arrays which are applicable for a complete 3D-mapping of interior rooms and offers a practicable way of determining the array position and direction related to the measurement object.

1 INTRODUCTION

Actual commercial beamforming systems, among them the Acoustic Camera, use a rectangular virtual image plane in order to calculate the run times between microphone array and measurement object (figure 1). This way the surface of the device under test is approximated, and the z-axis of the array is usually oriented perpendicularly to the image plane. Subdividing the image plane into rows and columns results in a finite amount of rectangular display details (pixels) whose centers of area are used to calculate the delays. Sound sources wich are placed on a three dimensional device surface will be localized and mapped on a two dimensional plane. This way causes two errors: At first, the focus of the beamformer is incorrect for most pixels. Dependent on array geometry, subsurface structure,

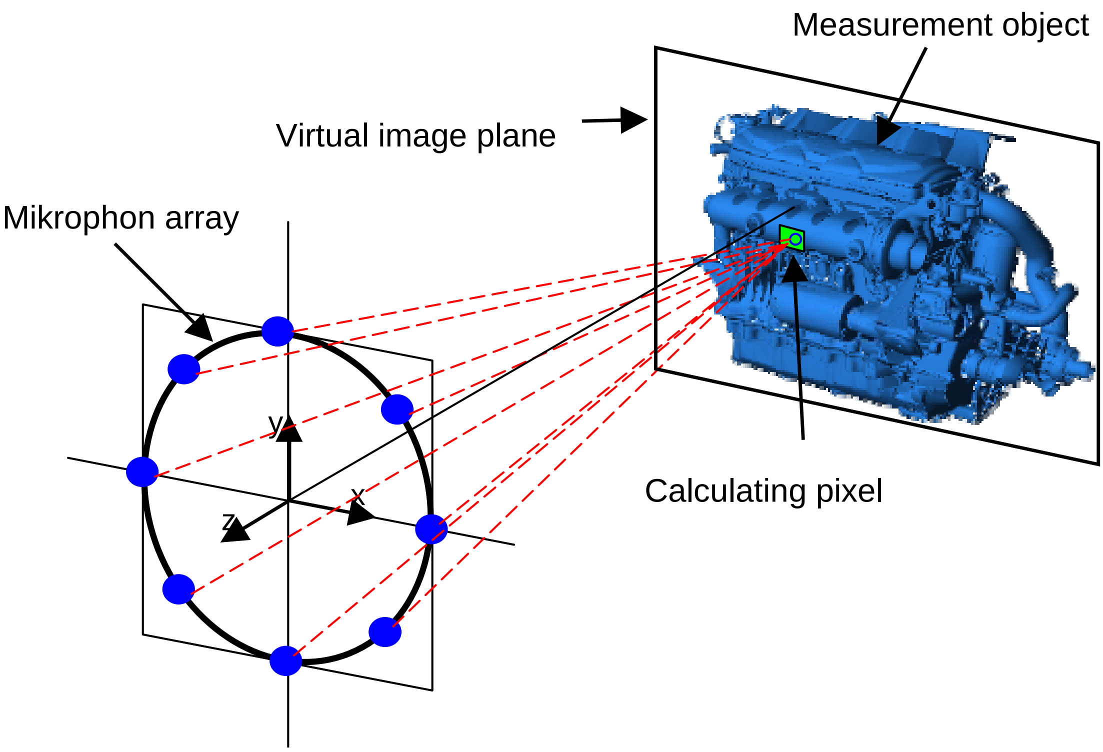

Fig. 1: Conventional beamforming and mapping onto a 2D virtual image plane

frequencies of the sound source and distance between array and object, the calculated level of sound pressure is different to the level calculated with correct focus. Second, by mapping the (incorrect) calculated sound sources on a two dimensional plane we will get distortions of the mapping. Sound sources will be localized incorrectly. In most beamforming applications these effects are negligible, but for mapping of interior rooms these effects are noticeable. An example is shown in figure 2.

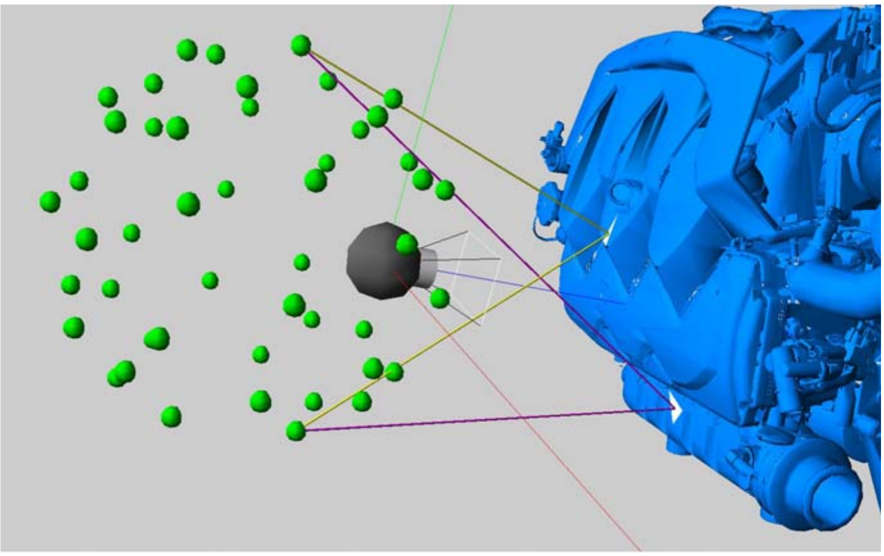

Fig. 2: Correct focussing of the beamformer to depth structured surface of measurement object

2 MAPPING OF 3D SURFACES

To resolve these problems, we replace the simple mapping of a virtual plane at a fixed distance by different measurement distances to individual points at a 3D-model surface. Of course, we need a 3D-model of the measurement object, preferably available in a standard CAD file format. In many sectors of industries, this precondition is fulfilled in most cases. 3D-models of engines, cars or airplanes usually consist of several hundred thousands of triangles. For the calculation of a three dimensional sound source distribution, this resolution is far too high with respect to the immense calculation times required and the unnecessary fine degree of resolution typically resulting. For this reason, the polygon models have to be reduced in resolution before the actual acoustic mapping takes place.

In 3D-mappings, the planar virtual surface subdivided in pixels is now replaced by lots of triangles definitely oriented in space and modelling the actual surface of the measurement object. Dependent on the desired acoustic resolution and the given graphical model resolution, those triangles may either be coloured directly or may themselves be subdivided into pixels (texturing). The time delays are now calculated in three-dimensional space for every individual triangle or for every individual subpixel of all the triangles, respectively.

The acoustic map of a 3D-model surface includes only the values from points respectively triangles which are really situated on the surface of the object, in contrast a mapping of a 2D virtual plane often includes calculated points beside the real object. If the beamformer is optimized to avoid sidelobes in the inner region of the visible image field, the mapping onto a 3D object often leads to seemingly better contrast values, because sidelobes in the outer region normally diminishing image contrast in the 2D case are now excluded from the calculation. On the other hand, if a real acoustic source is present in the image field which is not contained in the 3D-model, it is possible that this source or its sidelobes are erroneously mapped onto the surface of the 3D-model or they are not visible at all. Therefore, it is advisable to accompany every 3D-mapping by an additional 2D-mapping. A typical case of incorrect mapping is shown in figure 3 and 4.

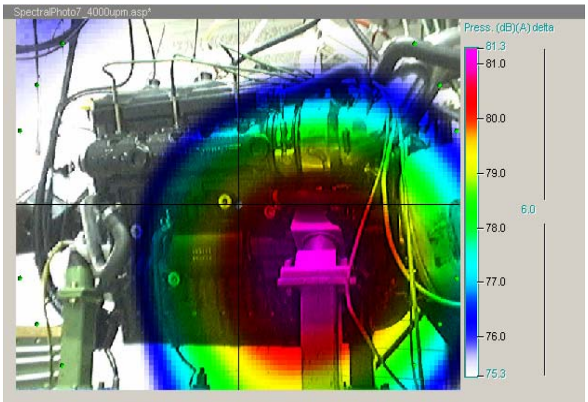

Fig. 3: 2D-mapping of a sound source caused by an unfixed mounting

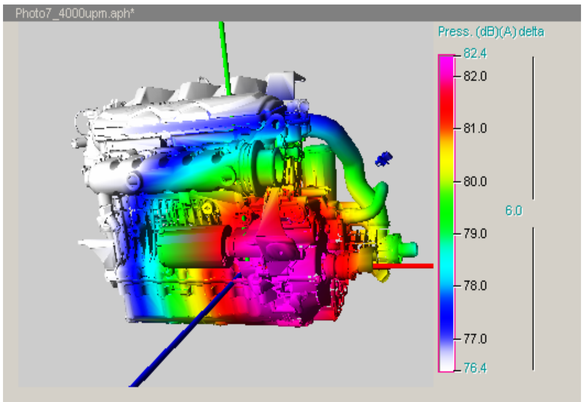

Fig. 4: The same measurement as Fig. 3, but mapped on a 3D-model.The result suggests a noise source situated on the engine

3 MAPPING OF CAR INTERIOR

3.1 Microphone arrays for use inside a car interior

In addition to the above mentioned precondition, for mapping interior rooms we need a suitable microphone array. Conventional planar arrays with a favored imaging direction are not able to perform undistorted 3D-mappings. The characteristics of the array (frequency response, resolution, sidelobes etc.) should be as identical as possible for all directions in space. An array having its microphones equally distributed on a (virtual) spherical surface and with the sensor's direction vectors perpendicular to this sphere will be adequate.

The frequency range of an array is depending on minimum and maximum distances between microphones. If we spread microphones on a virtual spherical surface, we need more microphones to get the same frequency range as a planar array.

In order to construct a spherical array there are two possible ways: solid sphere or acoustic transparent sphere. A solid sphere is easier in manufacturing. But it has some disadvantages: the soundfield will be disturbed, half the number of microphones is shadowed and the surface of the sphere will be generating reflections and frequency dependent errors in measurement results. Of course, the shadowed microphones also receive the acoustic waves from the noise source because the waves are diffracted around the sphere, but the diffraction and therefore the time delays are frequency dependent. These properties of a solid sphere enforce a calculation of the acoustic map in the frequency domain to correct these errors. The calculation of three dimensional acoustic maps in the frequency domain requires high computational power, and the analysis of non-stationary noise events is difficult and imprecise. Last but not least, the weight of a solid sphere may make the handling difficult. Therefore we use only acoustically transparent arrays. Some examples of spherical transparent arrays are shown in figure 5.

Fig. 5: Spherical acoustically transparent arrays with 48 channels and 120 channels and a built-in video camera

3.2 Determination of position and direction of arrays in car interior

A further important step is the determination of the coordinates and the orientation of the array in relation to the 3D-model. The precision of this fitting determines the quality of the results. To give an example, a rotation of the array of only 2 degrees will result in a location error of 0.07m at 2m distance. A determination of position and direction of the array with traditional measurement equipment (measuring tape, goniometer and so on) is impossible in a car interior. Therefore we use an advanced technique derived from photogrammetry. All arrays include a built-in video camera. If the array is placed inside the car, the video camera sends a video stream of the car interior. The software module for preparing three dimensional mapping receives the video stream and overlays the pictures with a 3D–model of the car interior. By moving and rotating the 3D model the pictures from video camera and 3D model are matched. If the exact match is found, the position of the microphone array in relation to the 3D-model will be determined. Measurement equipment is not necessary, all positioning problems are solved in software and with a built-in video camera. An example of the fitting in the various grades is given in figure 6.

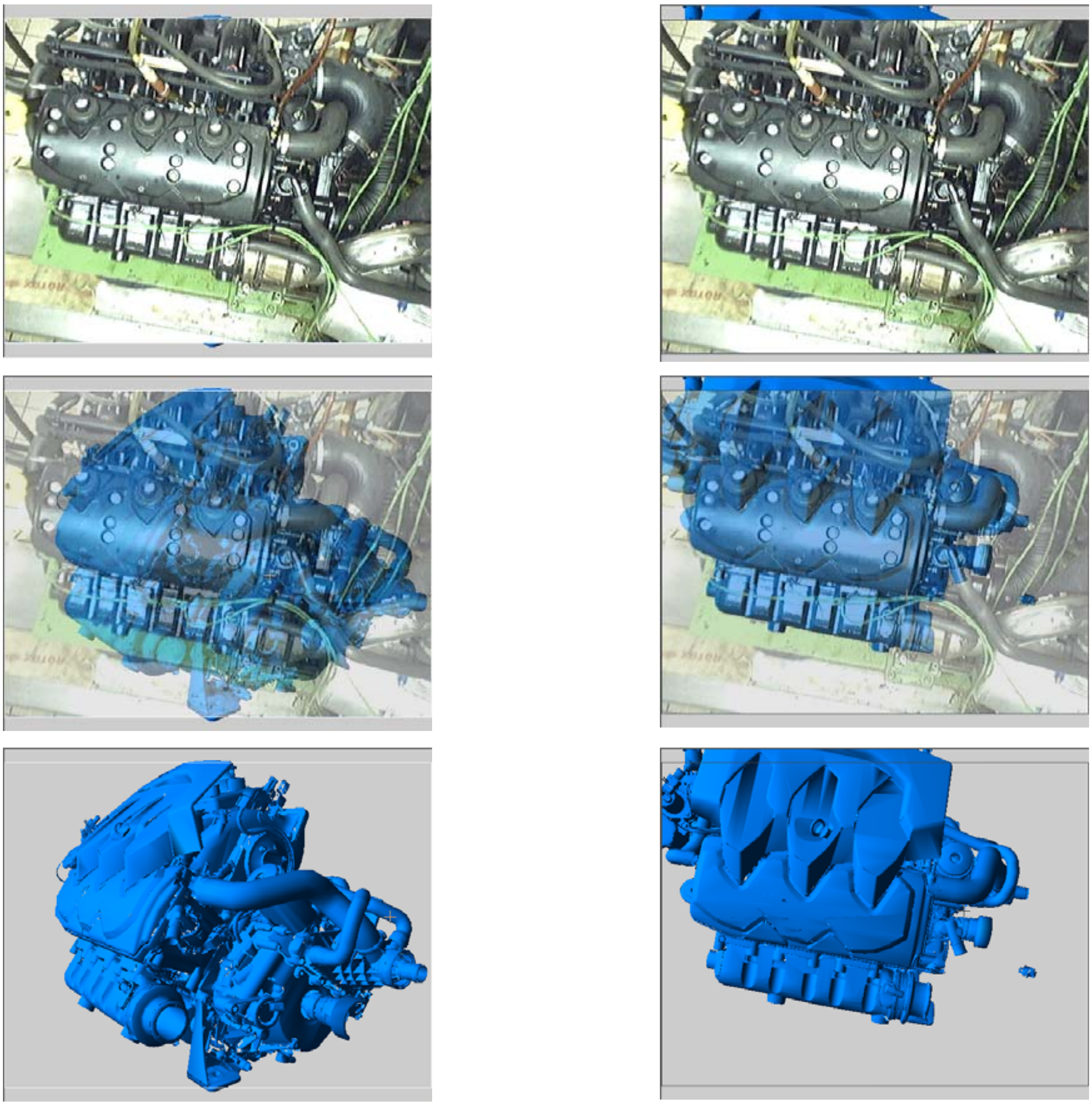

Fig. 6: view to the motor from the built-in video camera (left unmatched, right matched), the optical photos were displayed in various grades of transparency (from top: 0%, 50%, 100%)

4 CONCLUSIONS

Beamforming and mapping of a 3D-model surface expand and complete the conventional 2D-mapping on a virtual plane. Preconditions for 3D-mapping are a 3D-model of the measurement object and, for mapping of interior rooms, an omni-directional array. Sphere array having its microphones equally distributed on a (virtual) spherical surface accomplishes this condition. Acoustically transparent sphere arrays have some advantages in contrast to solid sphere arrays. A 3D-mapping can offer a better contrast in acoustic map, to avoid misinterpretation a 3D-mapping should be accompanied by an additional 2D-mapping. An easy to use and exactly positioning procedure is a precondition of 3D-mapping.

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