CONCEPT FOR A HIGH-RESOLUTION REAL-TIME CAPABLE 3D SONAR CAMERA FOR DEEP SEA OPERATION

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Abstract: *In this work we present a concept for a high-resolution real-time capable 3D sonar camera for deep sea operation. Simulation results concerning the acoustic setup as well as the operational mode of the camera are presented and discussed. Restrictions and limiting factors are described, potential solutions are illustrated. First measurement results of subcomponents are presented and compared to the simulation results for evaluation of the software modelling. Finally, the current status and the next steps are mentioned.*

Keywords: *SONAR, 2D Array, real-time, 3D imaging, beamforming, deep sea*

1. MOTIVATION

With its proceeding exploration the deep sea represents an increasingly attractive field for physical, biological, geological, archaeological as well as economic interests. Visualization tools which provide volumetric images of reasonable quality within an acceptable period of time are required in order to accomplish a comprehensive scientific exploration as well as an efficient economic utilization of the deep sea. As optical imaging systems are very restricted in the seafloor area due to the high concentration of suspended matter – especially during ongoing operations – acoustical imaging systems are the better choice in this field.

For this reason a high-resolution real-time capable sonar-system is required to ensure an adequate visualization for exploration and process monitoring purposes. To date there are very few volumetric data acquiring sonar-systems on the market which are not real-time capable in most cases and which are moreover not designed for deep sea usage. In addition, the spatial resolution of these systems is inadequate for many purposes.

The presented work deals with the development of a sonar-camera system which meets the requirements of this application field.

2. APPROACH AND SYSTEM OVERVIEW

The sonar camera is supposed to provide a spatial resolution in the region of few centimetres within short ranges (up to 15 m) and should ensure a sufficiently high frame rate (more than 10 frames per second). Furthermore, the camera needs to cover an adequately wide field of view in order to enable the visualization of processes without a continual realignment. Besides the electromechanical construction of the camera, aspects like suitable transmitting and receiving strategies as well as efficient data processing strategies are essential for the proposed device.

The acoustic antenna constitutes the centrepiece of the proposed camera system and essentially determines its performance. A two-dimensionally structured array with 1024 single elements was chosen to form a combined transmitting and receiving antenna. The centre frequency was designed to be 1 MHz in order to ensure an appropriate spatial resolution as well as an acceptable propagation loss. A pitch of 2λ (3 mm) constitutes a compromise between the lateral resolution and the expanse of the visual field. The described antenna shows an aperture of 96 x 96 mm^2.

Actually, the antenna is supposed to insonify its maximum lateral imaging range, which strongly depends on the geometry of a single element. However, this sector can be specifically decreased by modifying the transmitting delays in order to increase the acoustic pressure in a certain field of interest which leads to an increased contrast level for this region.

The generation of the excitation signals as well as the digitalization of the received ultrasound signals will be performed by an electronic system which consists of a sonar beamformer with 128 channels [1] and an 8:1 multiplexing device. The pressure tolerant assembly system which has been approved in former projects should also be used for the mentioned sonar-camera [2]. For evaluating the deep sea suitability of the camera system, a pressure chamber which can be driven to a maximum test pressure of 600 bar and also allows functional tests of the camera under pressure is available.

3. SIMULATION AND EXPERIMENTAL RESULTS

By means of several different software simulation tools, possible design and operation concepts have been comparatively evaluated.

The *Scalp* software package (developed by the Fraunhofer IBMT) is based on the point-source-synthesis and allows the prediction of sound pressure fields depending on several transducer characteristics. By defocussed excitation of the single antenna elements, a 30° sound field opening angle (at -3 dB) can be achieved in elevational as well as azimuthal direction. This corresponds to the insonification of a field with an edge length of 5 m x 5 m at 10 m distance from the aperture (Fig. 1).

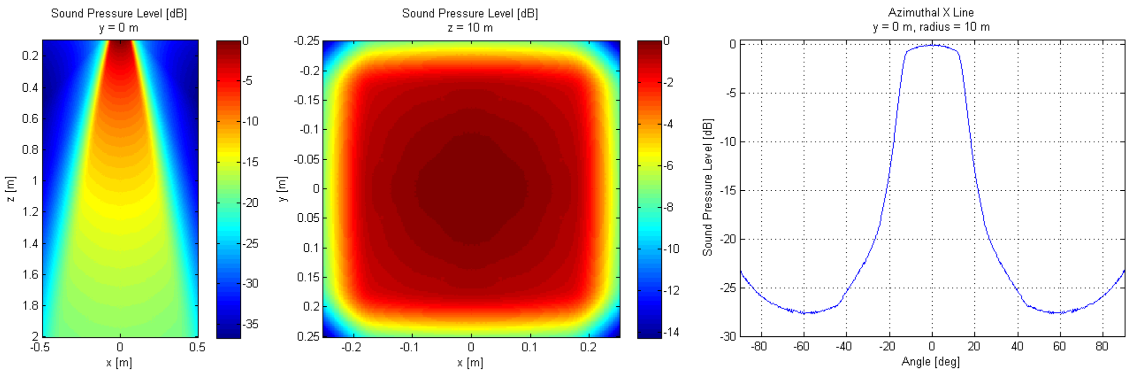

Fig. 1: Simulated sound field and azimuthal x line

The maximum achievable opening angle of the antenna is determined by the opening angle of a single element. This angle can be approximately calculated by the following equation [3],

$$\Theta_{-3dB} = 2 \cdot \sin^{-1}\left(0.44 \cdot \frac{\lambda_W}{e}\right) \tag{1}$$

where λ_W indicates the acoustic wavelength in the propagation medium (in this case water) and e is the edge length of the transducer element.

Using the *Field* software package [4], simulations concerning the reconstruction of a point reflector have been performed. With these simulations, the lateral and axial resolution of the antenna as well as the reconstruction artefacts could be investigated.

Initially the artefacts due to trailing sound waves have been very strong, but with the aid of a transmitting apodization of the antenna elements, these artefacts could be efficiently suppressed (Fig. 2). However, the simulations show that the usage of a transmitting apodization leads to a reduction of the antenna's sound field opening angle. Therefore, a compromise has to be made in case of doubt, between the size of the insonified area and the quality of image.

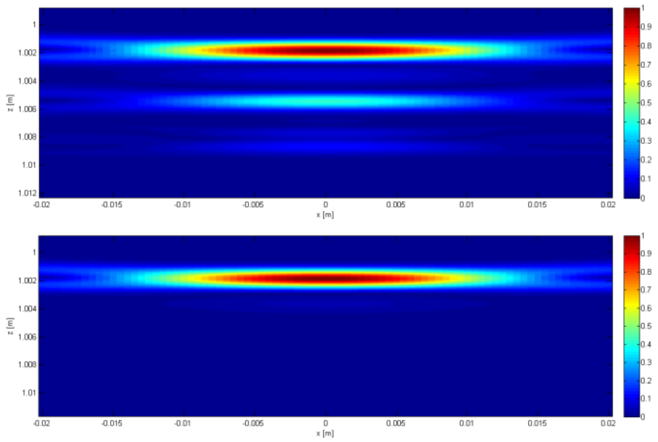

Fig. 2: Reconstructed point source without transmitting apodization (above) and with transmitting apodization (below)

In order to determine the spatial resolution of the antenna, the point spread function (PSF) was calculated. It describes the system's response to a point reflector within the insonified and reconstructed volume. The point reflector was placed on the centreline in front of the antenna at a distance of 1 m. After the image has been reconstructed, an axial and lateral projection onto the vertical and horizontal axis was accomplished in order to measure the -6 dB lateral and axial width of the PSF (Fig. 3).

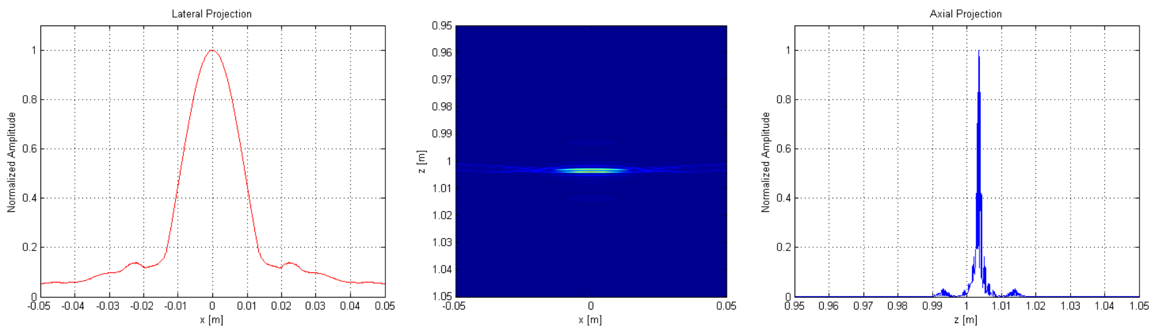

Fig. 3: Lateral and axial projection of the point spread function (PSF)

At this position of the point reflector the lateral resolution of the antenna was calculated to approximately 18 mm while the axial resolution was computed to less than 1 mm (using a single cycle sinusoidal burst as excitation signal). The spatial distribution of the axial and lateral resolution within the sound field are shown below (Fig. 4).

Additional simulations show that the usage of frequency coded excitation signals combined with a matched filtering of the received signals leads to a significant increase of the SNR which allows it to make use of even heavily noisy receive signals in order to perform an acceptable reconstruction. Moreover, this method allows it to use longer sound signals without compromising the axial resolution of the system. Consequently more acoustic energy can be brought into the propagation medium resulting in a higher image contrast.

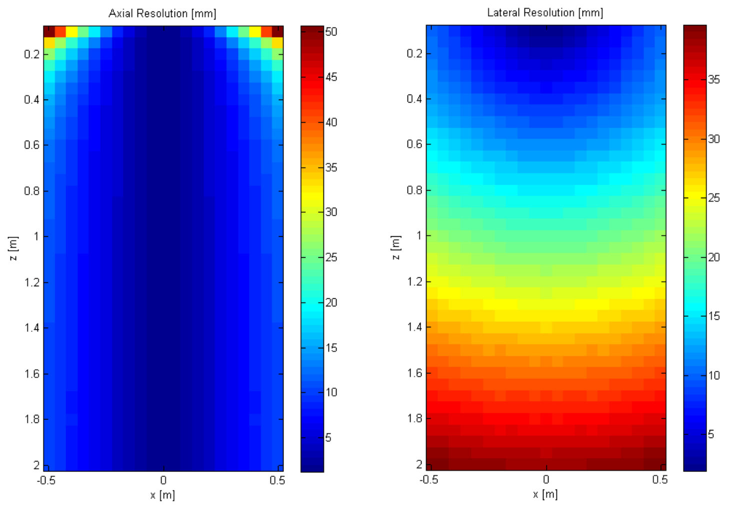

Fig. 4: Spatial distribution of the antenna's axial and lateral resolution

With the aid of the *PiezoCAD* software package (Sonic Concepts) several different piezoceramic materials have been evaluated concerning their performances. The acoustic matching layers have been selected in compliance with the KLM theory [5]. According to the simulation and measurement results, the most suitable transducer setup for the proposed application is a 3-1 composite of NCE 55 material (Noliac Piezoceramics) due to its relatively low electrical impedance and high values of ε_r and d_{33}.

In the simulation, this transducer achieved a bandwidth of approximately 80 % at a centre frequency of 1 MHz, which was exceeded in the experimental pulse echo measurement (Fig. 5).

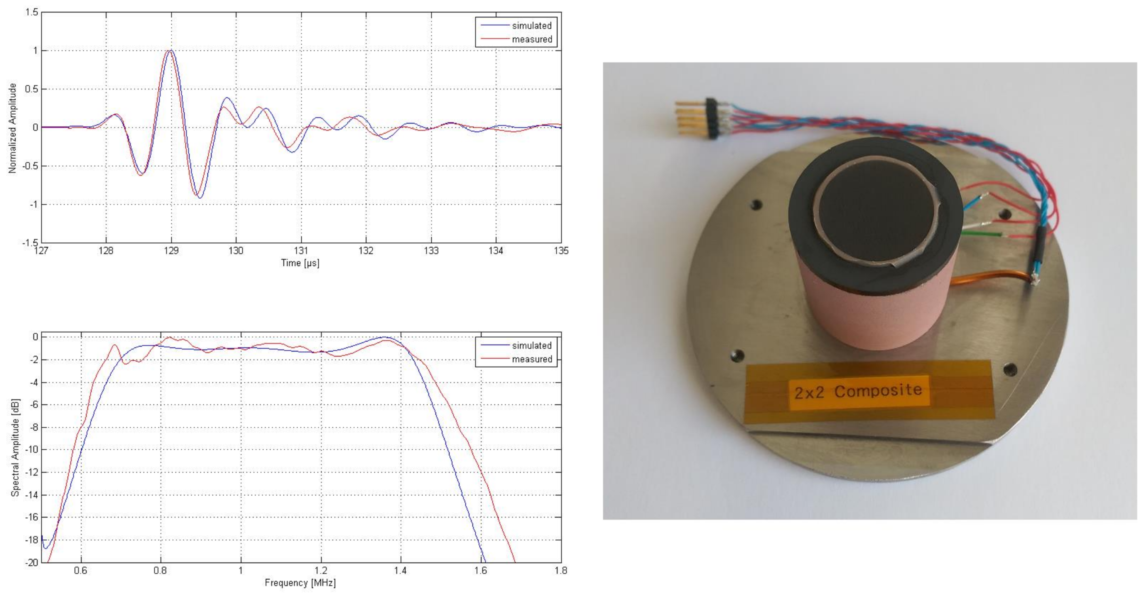

Fig. 5: Simulated and measured receive echo waveform and frequency spectrum of the test transducer

4. CONCLUSION

In this work, the sound field characteristics of a sonar antenna have been simulated and first measurements of subcomponents have been performed. By the aid of several software packages, a concept for the antenna could be found which is suitable for the purpose. Simulations concerning the sound field, the resolution and the artefacts contributed to adjust different design and operational parameters, such as frequency, pitch, piezoelectric material and the beamforming methods. A spatial resolution of approximately 18 mm at a distance of 1 m is feasible with this setup. Using a defocussed excitation of the antenna elements a maximum sector of about 30° x 30° can be insonified.

Currently, a first prototype of the camera is under construction (Fig. 6). The next step will be the initial operation of the whole camera system in an experimental setup in order to perform first measurements. However, the final system should provide a high order of integration where all components necessary for the generation and output of the images are placed in one compact and deep sea suitable housing.

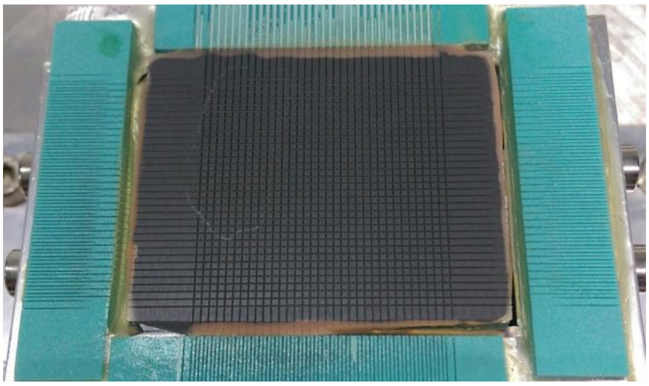

Fig. 6: First prototype of a 2D array with 1024 elements

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