Microphone Array 3D Acoustic Imaging

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ABSTRACT

MICROPHONE PHASED ARRAYS, COMMONLY KNOWN AS ACOUSTIC CAMERAS, ARE USED BY INDUSTRIES SUCH AS THE AERONAUTICAL, AUTOMOBILE AND CONSTRUCTION INDUSTRIES TO MEASURE THE MAGNITUDE AND LOCATION OF NOISE SOURCES. THESE ACOUSTIC IMAGES ARE COMMONLY OBTAINED USING BEAMFORMING AND DECONVOLUTION ALGORITHMS. TRADITIONALLY, THESE ACOUSTIC IMAGES USE 2D IMAGING PLANES. HOWEVER, THIS CAN LEAD TO ERRORS IN THE NEARFIELD FOR 3D OBJECTS DUE TO INCORRECT BEAMFORM FOCUSING. THIS PAPER OUTLINES THE DEVELOPMENT OF A 3D SCANNING MICROPHONE ARRAY THAT AUTOMATICALLY CORRECTS FOR 3D OBJECTS AND PROVIDES THE CORRECT ACOUSTIC IMAGING FOCUS. NEW TECHNIQUES FOR PROCESSING THESE 3D IMAGES ARE ALSO DESCRIBED.

INTRODUCTION

Acoustic noise is an issue for many industries. Usually, noise is measured using a single microphone. This gives the magnitude of the noise level but does not provide information about the location that the noise is coming from. Microphone phased arrays, commonly referred to as acoustic cameras, have been developed to find both the magnitude and the location of sound sources. They are used by a range of industries such as the automotive and aeronautical industry to identify the location and magnitude of unwanted sound sources. This is then used to mitigate these noise sources [1-3].

Acoustic cameras have used algorithms such as beamforming to calculate the sound intensity at specific scan points. Traditionally, acoustic cameras have used a 2D scanning surface (grid of scan points) that is usually oriented perpendicular to the array's Z-axis and located approximately at the same distance from the array as the object [4, 5]. It has been shown that this traditional 2D method can result in errors in the near field if the sound source does not lie on the 2D plane [3, 4]. This issue can be resolved by using a 3D scanning surface that corresponds to the surface geometry of the object being imaged [5].

The 3D scanning surface can be obtained using a CAD model of the object. The resulting acoustic images may then be overlapped on the CAD model to display the noise sources on the object [6]. However, this method requires a CAD model of the object to be available and also requires an alignment process. An automated method of obtaining the 3D scan points is desirable. To address this, laser scanners have been used to obtain the 3D scanning surface for 3D images. However, this is a generally costly option. Legg and Bradley used a structured light technique to automatically obtain the 3D scanning surface for an acoustic camera [4].

Chiariotti et al used the Microsoft Kinect to obtain a 3D scanning surface for the microphone array imaging of the interior of a car cabin [2]. However, the Kinect was not attached to the array but placed behind it. They used an average beamforming technique that reduced the effect of echoes. Heilmann et al. used several 3D cameras including the Structure Sensor, which they integrated into an acoustic camera and used to create 3D acoustic maps [7]. Concurrently and independently of the above work, a similar 3D scanning acoustic camera system was developed at Massey University, Auckland. This conference paper describes work performed developing this camera and recent work performed to improve this system.

HARDWARE

The acoustic camera consists of three individual elements; a microphone array, Structure Sensor 3D camera, and a Windows Surface Pro Tablet. The entire device is presented in a portable hand-held form factor and can be operated by a single user. A high-level overview of the presented system can be seen in Figure 1.

Figure 1. High level overview of acoustic camera used in this paper.

The microphone array was designed and developed for the visualisation of high frequency audible sound, upwards of 1 kHz. Given the size restrictions of the overall device and number of ADC channels available, an iterative optimisation procedure was developed using MATLAB to optimise the placement of the microphones. The software was able to simulate microphone array performance in terms of beam width and sidelobe attenuation. Square grid and spiral arrays were tested with different microphone counts and shape. With this optimisation procedure, the precise number of microphones and shape of the final array was determined. The final placement of the 25-microphone array can be seen in Figure 2. To reduce cost, the array was constructed out of five identical PCBs. These were combined to form the final array. An example of one of these can be seen in Figure 3.

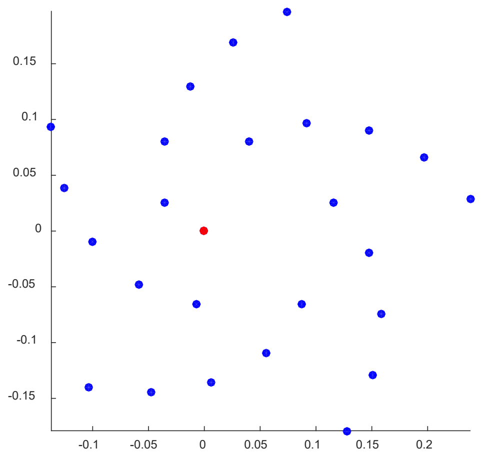

Figure 1. Optimal microphone positions determined by the iterative matlab simulation.

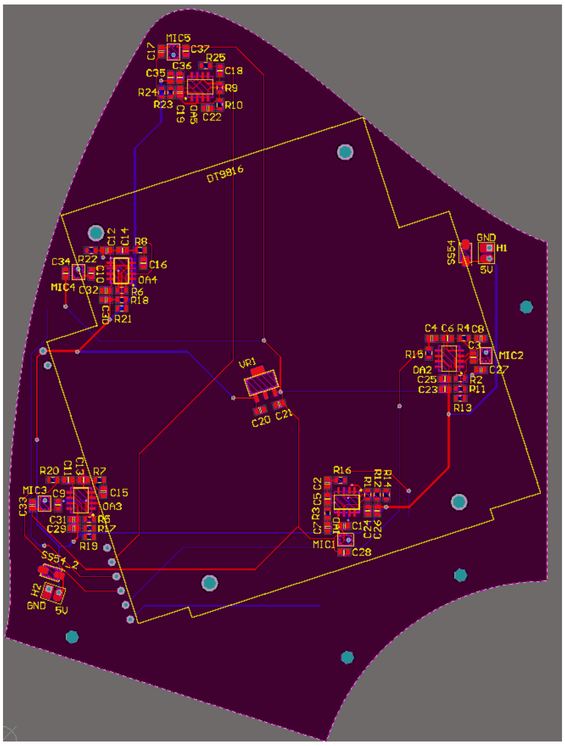

Figure 3. One of the five PCB sections that make up the microphone array.

Each microphone was individually amplified and bandpass filtered with a collocated amplification stage. Important consideration was taken to optimise PCB layout for each microphone to reduce noise and the influence of any outside interference. *Data Acquisition* DT9816 devices were used to capture the amplified microphone signals at a sample rate of 50kHz. These were primarily chosen for their high bit depth and compatibility with MATLAB. Four DT9816 devices were used. Each was mounted to the back of the main microphone array.

The combined depth information from the 3D camera, and audio recordings from each individual microphone are processed using a real time MATLAB program. An example of the resulting 3D acoustic scan can be seen in Figure 4.

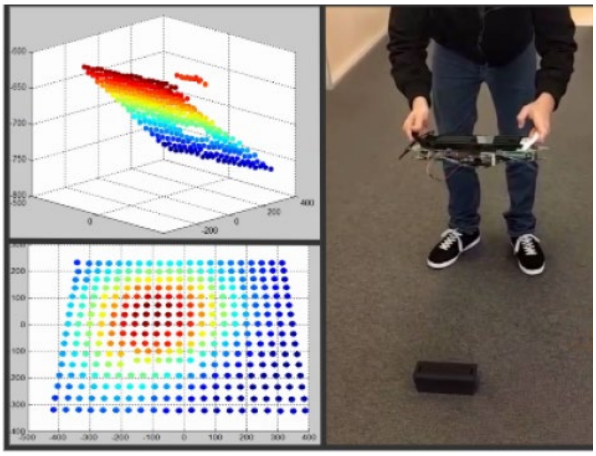

Figure 4. 3D acoustic scan of a speaker placed on the floor. The speaker is emitting a single tone 1kHz signal.

IMPROVEMENTS ON THE SYSTEM

The integration of 3D scanning technology with microphone phased arrays has potential to significantly improve accuracy in the near field for 3D objects and increase ease of use. However, more work is needed in this area. In our work, we found visualisation of the acoustic map over the 3D scans and syncing of the camera with the microphone data was challenging.

A disadvantage of the 3D camera that we used (the Structure Sensor) was that it did not produce a coloured point cloud and it could not be used in direct sunlight. The depth camera was, therefore, changed to the Intel Real Sense D415 camera. This was smaller, could operate in direct sunlight, and produced a coloured 3D point cloud point cloud. Combining the coloured point cloud with the resulting 3D acoustic has the potential to allow improved visualisation. The Intel camera also has a pin that outputs a trigger signal. This can be used as a hardware trigger to sync the acquisition of the microphone data with the depth camera.

It was also desirable to be able to merge 3D acoustic maps taken from different locations. Ideally, one should be able to move around a 3D object with the acoustic camera and the resulting 3D acoustic map be automatically merged into a single 3D maps and averaging perform where the merged maps overlapped.

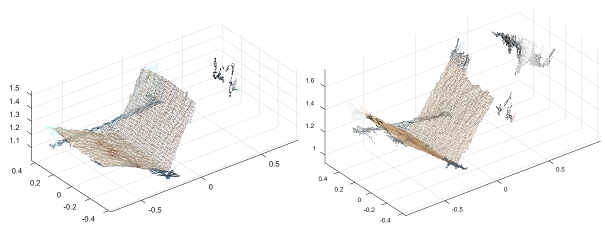

Figure 5. Point cloud images of the plywood box, taken from two different angles.

To address this, initial work has been performed using iterative closest point algorithm to merge the 3D camera scans of an object, which were obtained from different positions. Initially, two point cloud images of plywood box were measured from different angles using the 3D camera, see Figure 4. The first point cloud was set as the reference frame for the second point cloud image. Then iterative closest point algorithm was used to transform and align the point cloud data to produce the results displayed, see Figure 5. This technique would allow 3D beamformed maps taken from different views to be merged and averaging performed.

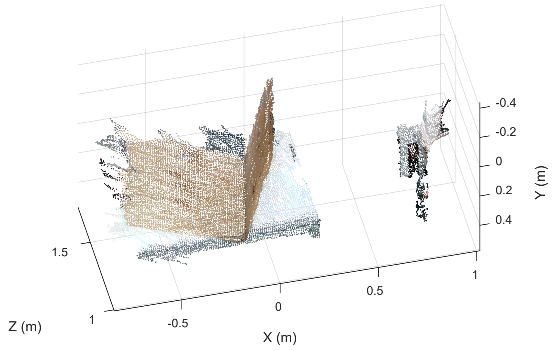

Figure 6. Merged point cloud image.

Conclusion

This paper describes the development of a microphone array that automatically captures the 3D surface of objects and hence provides the correct acoustic imaging focus. New techniques for processing 3D imaging are also described.

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