Rapid high resolution 3D intensity measurements with a stereo camera system

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Abstract

The flow of sound energy is often unknown because it is influenced by all sound sources and reflecting surfaces present. Simulations require much calculation power, and small details existing in reality are usually disregarded. Instead, the sound intensity can also be measured. Studies with three-dimensional intensity tests at many positions revealed that complicated sound intensity fields can exist even around the simplest structures. However, most test procedures are rather involved and time consuming. This paper presents a quick procedure involving an optical system that detects the orientation and position in three dimensions of an intensity probe that is scanned throughout space. Results of tests performed around a monopole loudspeaker, a compressor, and an UAV will be presented and discussed.

Introduction

To determine radiated sound levels one dimensional sound intensity tests are often performed. When all three components of the intensity vector are measured also directional information is obtained. By measuring the three-dimensional intensity at multiple positions, the energy flow throughout space can be determined.

For many years sound intensity has been measured with PP probes comprising of pair(s) of closely spaced microphones. Nowadays, intensity can be also measured with a PU probe consisting of a microphone and one or multiple particle velocity sensor(s). Unlike PP probes, PU probes have no spacing problems, can easily be extended to full 3D probes, and can be used in environments with high levels of background noise or reflections [1, 2]. For the tests presented in this paper a three-dimensional PU probe is used.

An error indicator for PP probe tests is ratio of sound pressure squared to active intensity. Test results are valid only when this pressure-intensity index is below a threshold. However, determining the pressure-intensity index can be difficult because the calculated intensity might be incorrect. PU probe based intensity tests are complicated when the reactivity, which is the ratio of reactive to active intensity, is high. Yet, this reactivity depends on the phase between sound pressure and particle velocity, which is measured accurately. Intensity values can therefore be omitted if the phase exceeds a certain value.

Sound energy tests involve many intensity measurements. In early methods the data was acquired point-by-point, which was rather time-consuming method [3]. In [4] fast procedure was used, involving an optical camera tracking the position of a probe that is scanned through a plane. However, the position in the plane and orientation of the probe are hard to control accurately. In this paper, a method is presented to capture the 3D position and orientation, allowing free movement of the intensity probe. The equipment used will be described and results of several tests will be shown.

Stereo camera 3D positioning system

In the method presented here an intensity probe is scanned throughout space to acquire many measurement point quickly. For determining the position and orientation of the probe over time. A tracking system is used which measures six degrees of freedom, i.e.: position in three directions (x, y, z) and three angular coordinates (α, β, γ).

The tracking system consists of two cameras and a lamp emitting infrared light, see figure 1. Spherical retro-reflector markers are attached to the intensity probe. The marker reflections are detected by cameras, and the internal processing of the tracking system calculates the 2D marker position in image coordinates. Using multiple cameras, the 3D position of each marker can be derived.

Advantages of using such an optical tracking system are that it is unaffected by nearby metals as is the case with magnetic systems, there are no drift problems as experienced with inertial sensors, and the probe can be moved freely without additional electronic systems mounted to it. A high spatial resolution can be achieved depending on the amount of markers used and their size, the camera view angle, and the measurement distance. For example, a root mean square error of <0.5mm in position and <1 degree in orientation can be achieved with a grid of 7mm diameter markers up to a 2.5m distance from the tracking system. The tracking can be done real time and with a sample rate of maximally 120Hz.

Figure 1: Stereo camera system tracking the movement of spherical reflectors attached to a 3D intensity probe.

Measurements

In this section examples of several sound energy flow tests are shown. The used measurement procedure is as follows. A 3D intensity probe is scanned around a noise emitting object. During this test the probe position is captured with the optical tracking system installed at a distance. The duration of most tests was about 5 minutes.

The spatially distributed intensity values are calculated by a procedure that is similar to the one described in [4]; the measurement volume is divided into an amount of grid cells. Whenever the probe enters a grid cell for a sufficient amount of time to calculate the intensity that data is attributed to the cell. Multiple intensity values in one cell are averaged to reduce noise. A grid cell size of 5cm x 5cm x 5cm is chosen to allow a high resolution while sufficient time data is attributed to most grid cells.

Finally, the results are visualized using a variety of plot methods. As geometric reference a 3D CAD model of the test object is used here. Alternatively, the geometry might have been obtained by scanning its surface with a pointer that is tracked with the same system as is used for tracking the probe.

As mentioned earlier, the error of PU based intensity tests increases if the phase between sound pressure and particle velocity is high. Following the boundary identified in [1] intensity values are omitted when the phase exceeds 72 degrees.

To validate the procedure a monopole loudspeaker has been tested in a room with few reflections. Figure 2 shows that all intensity vectors point away from the source at 500Hz and that the intensity levels decrease with distance from the origin, just as would be expected. At 8kHz the source becomes more directive towards the top which is also measured.

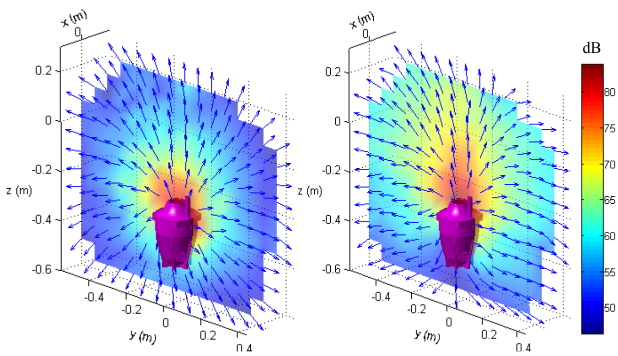

Figure 2: Intensity vectors and colour maps in a vertical plane of a monopole loudspeaker for 500Hz (left) and 8kHz (right).

The next two pictures show examples of tests with a compressor on a square base and a UAV. It can be seen that the sound intensity vectors do not always point away from the source. Depending on position and frequency the sound energy flow may be affected by reflections from surrounding surfaces.

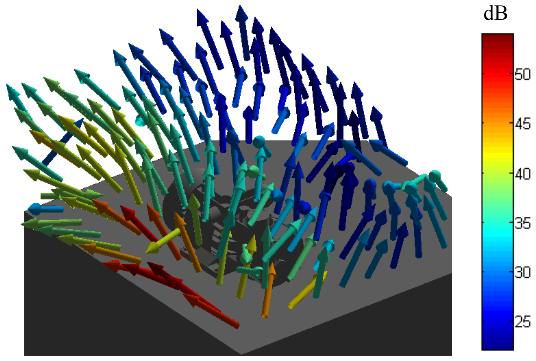

Figure 2: Intensity vectors around a compressor at 2.5kHz.

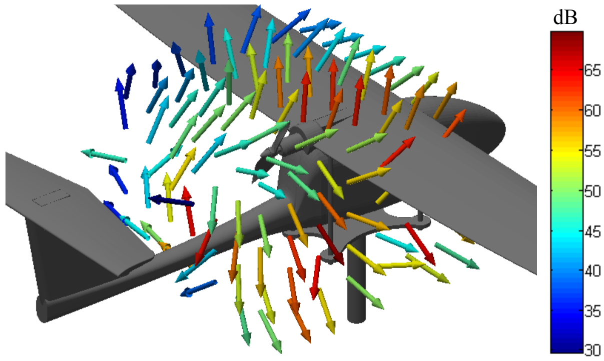

Figure 3: Intensity vectors around a UAV at 1kHz.

Conclusions

A method is presented to quickly measure sound energy flow distributions. A 3D intensity probe is used that is small, requires no spacers, and is usable in environments with background noise and reflections. During the test the probe is swept around the sound radiating object while its position is captured with an optical system that tracks a set of infrared reflecting markers that are attached to the probe. The obtained intensity vectors can then be visualized in several ways. Results of three tests have been presented.

With the presented method more insight can be obtained in the way sound energy propagates from the source, which could be helpful for reducing noise, e.g. by identifying optimal locations for additional sound absorbing or reflecting materials. This research has aided the development of a commercially available sound energy flow test system.

Literature

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