INTERNATIONAL DESIGN CONFERENCE - DESIGN 2006
Dubrovnik - Croatia, May 15 - 18, 2006.

DESIGN 2006

INNOVATIVE INTERFACE FOR HUMAN-COMPUTER INTERACTION

W. Rolshofen, P. Dietz and G. Schäfer

Keywords: acoustic sources, man-machine, contact technology

1. Introduction

No other sense organ enables human beings to capture quick new information than with their eyes. So, complex proceedings are presented illustrative. Can acoustic sources be made visible like an optical hologram?

This question is researched in the EU-project “Tangible Acoustic Interfaces for Computer-Human Interaction (TAI-CHI)” [Ref. TAI-CHI 2005]. At the moment, this method is under development and will be implemented in various computer applications of the consortium. Finally, new applications for Human-Computer Interaction (HCI) shall be available on the basis of acoustic waves.

2. Acoustic source localisation methods

Aim of the project is to design a tangible acoustic interface. It shall detect the acoustic properties of an object, due to its vibration as a consequence of interaction (knocking, tapping etc.). Principally, there are two kinds of stimulation of physical objects: passive and active modes. In the passive mode any change in the acoustic properties of an object, due to its vibration as a consequence of interaction (knocking, tapping etc.), is detected and then used to estimate the location of the interaction. With regard to the active mode, the absorption of acoustic energy at the contact point of an object surface must be ascertained.

Currently [Rolshofen, Dietz 2005] there are three passive methods under investigation for tangible acoustic interfaces: time delay of arrival (TDOA), time reversal and acoustic holography, which is the detection method described in this article. Contrary to the known respectively applied method of acoustic holography in air, research results of this paper deal with a new approach, where holographic back projection is used in solid that is to mount the sensors directly on the surface of the material.

2.1 Introduction of holographic principle

Gabor formulated the idea of optical holography for the first time [Gabor 1948]. Many related inventions (e.g. laser) were needed before the principle was proved experimentally. A holographic picture is created by interactive information of the same source and then reconstructing their recordings in three-dimensional space. If a wave front propagates through an object point, a new spherical wave is built according to the Huygens-Fresnel’s principle. This is called the object wave contrary to the first existing reference wave. The superposition of the amplitudes and the phase distribution can be recorded on a photosensitive plate (see Fig. 1).

The main advantage of holography is that it can produce the vast information contents of holograms. This is because a three-dimensional wave field can be reconstructed from two dimensional photosensitive surfaces using the saved phase information [Roye 1987].

2.2 Theoretical description of Acoustic Holography

In acoustic holography, a two-dimensional sound pressure field is stored and used to determine the three-dimensional sound pressure field, which can be the field of the particle velocity, the field of acoustic intensity vector, the field of surface velocity and the field of the intensity of a vibrating sonic source [Maynard 1985].

In general, the acoustic holography is a measurement of a sonic wave field on a suitable surface and uses the measured two-dimensional acoustic wave field to reconstruct a three dimensional acoustic intensity distribution. A holographic reconstruction is just the convolution (deconvolution) of the measured values with the values of the measured Green's function [Williams 1999].

The main approximation, that the sonic source creates a wave field Ψ (r,t), can be described with the following wave equation.

$$\nabla^2\Psi(\mathrm{r},t) - \frac{1}{c^2}\frac{\partial^2\Psi(\mathrm{r},t)}{\partial t^2} = 0 \tag{1}$$

There is ∇^2 the Laplace-Operator and "c" a constant propagation velocity. In order to process the equation (1) more approximations are needed, such as the assumption of the existence of an infinitely dimensional surface surrounding the target area.

Also, the following Helmholtz equation with the wave number $k=\omega/c$ must be fulfilled. Results in the complex wave field can be obtained by applying the Fourier transformation to the above equation (1). The value of the amplitude and phase in the new equation depends on the distance between the positions of a measurement to the source "r". For the spatial analysis a constant frequency value ω is normally adopted in order to make a wave field satisfy the requirements of the Helmholtz equation.

$$\nabla^2\widetilde{\Psi}(\mathrm{r},\omega) + k^2\widetilde{\Psi}(\mathrm{r},\omega) = 0 \tag{2}$$

2.3 Rayleigh-Sommerfeld algorithm

With the increment of the distance between the source and the recording plane, further approximations become necessary. Concerning the tangible acoustic interfaces, the Rayleigh-Sommerfeld approximation is promoted which is referred to Rayleigh's integrals and Sommerfeld's radiation condition. It is the most general and valid formula which can be applied through out in the entire space.

A mathematical model of Huygens-Fresnel principle can be deduced from the Rayleigh-Sommerfeld diffraction formula, because this corresponds to the convolution integral. With regard to convolution theorem, convolution is just a multiplication in the Fourier space. From the analytical computation of the transfer-function (Green's Function), the wave propagation between hologram level and picture level can be calculated and displayed with the following formula (Rayleigh-Sommerfeld Algorithm) [Rolshofen, Yang 2005].

This is the holographic reconstruction of the complex wave field $\widetilde{\Psi}(x_B, z_B)$ with the hologram data $\widetilde{\Psi}(x_H, z_H)$, where F symbolise the Fourier and F^{-1} the inverse Fourier transform. Besides, the spatial co-ordinates are given with x and z, as well as the wave number k.

$$\widetilde{\Psi}(x_B, z_B) = \mathrm{F}^{-1}\left\{\mathrm{F}\left[\widetilde{\Psi}(x_H, z_H)\right]\cdot \mathrm{e}^{\mathrm{ikz}\sqrt{1\text{-}\lambda^2\left(\gamma^2+\delta^2\right)}}\right\} \tag{3}$$

In equation (3), the indices B and H indicate the source plane and the hologram plane respectively, λ is the wavelength, and γ and δ describe the associated local frequencies.

The purpose of acoustic holography is the reconstruction of wave fronts by their amplitude and phase distribution. Therefore, a phase shift in the wave propagation along the plate can be observed by the sensors and reveal the position of each source simultaneous.

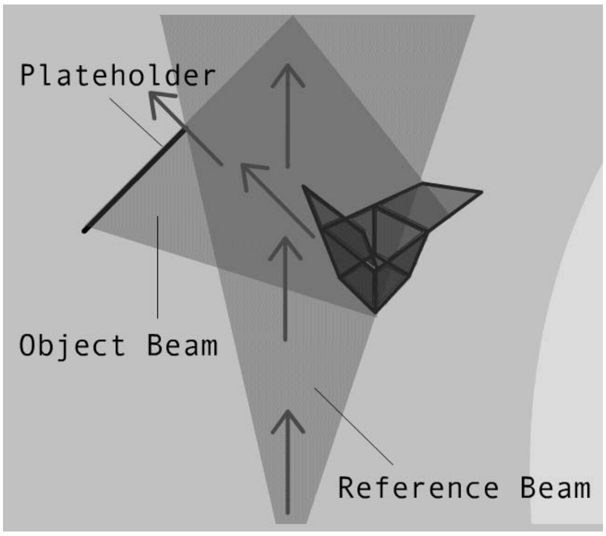

Figure 1. Superposition of object- and reference beam on a photosensitive plateholder, where an optical hologram is created [Ref. MIT 2002]

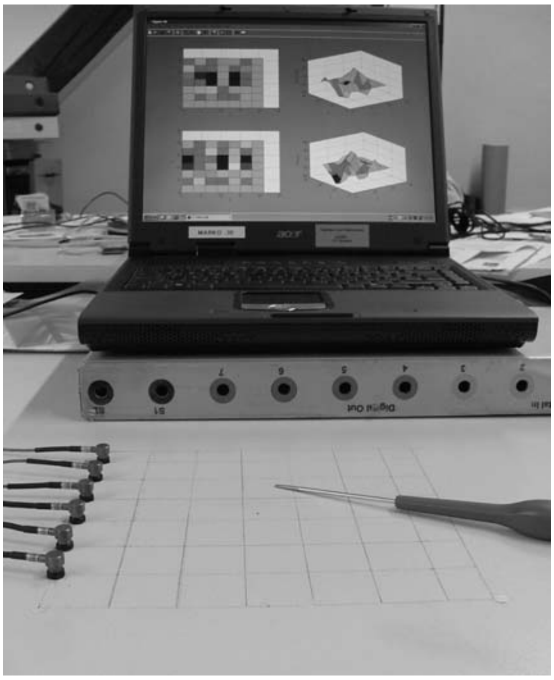

Figure 2. Photography of test equipment and result of source localisation

3. Operation

Based on the Rayleigh-Sommerfeld Algorithm, a Matlab programme was written to localize the acoustic source. The used equipment contains ICP accelerometers, which are connected via a National-Instruments data acquisition card with a mobile computer. On the machine runs the Matlab code. As a test object, the sensors were mounted on a wooden writing table. A picture of this experimental setup can be seen in Fig. 2.

Firstly, a hit on the table with a screwdriver is detected by the acoustic sensors, which are arranged along a line. This means to start with the recording of the runtime of each signal (see Fig. 3, left) after signal amplitude is above a specific trigger threshold. Due to the idea of phase shift detection, which holography is taking advantage of, a Fourier-Transformation is applied on the time data. Afterwards, both amplitude and phase spectrum of these signals are calculated (see Fig. 3, right) and it can be seen that most of the energy belongs to propagating waves with frequencies between 500 and 3000Hz.

Next, due to the fact that wave propagation velocity has to be known, the average propagation velocity in the object of interest was estimated in a previous measurement. The method for this calculation is based on arrival times of first signals along a known distance. On that condition, the algorithm is ready for the transformation, which leads to the back projection along the wave path.

Finally, the Rayleigh-Sommerfeld Algorithm is calculated for different frequencies, which have maximum energy content according to amplitude spectrum. With reference to equation (3), hologram data is the originally recorded runtime signal.

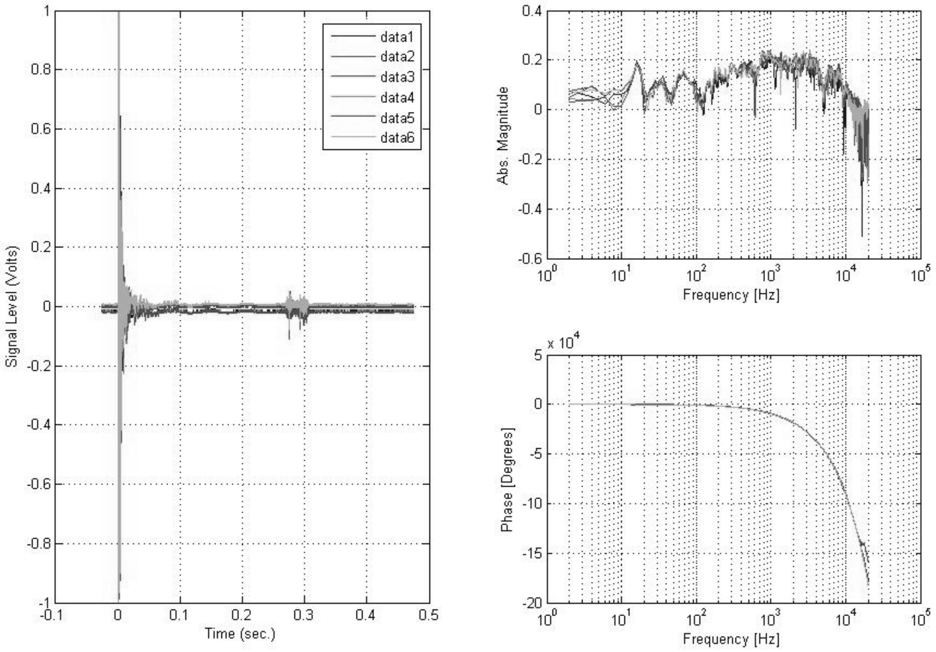

Figure 3. Left-hand side shows signal [Volt] vs. time [sec.], whereas right-hand side shows amplitude and phase spectrum of acquired data

4. Outcome

In Fig. 4 and 5, the estimated result of source localization with Rayleigh-Sommerfeld Algorithm is presented. For the frequencies 600 and 1600 Hz, a back projection was calculated. On the writing table was a grid to co-ordinate the tapping or knocking, what occurred in that example at x-co-ordinate 10 and z-co-ordinate 10.

For both frequencies shown, a maximum in amplitude distribution can be observed (darkest area in figures). This correlates with the tapping position (circle) more or less. The error is not more than a neighbouring square. Presumably, the reason for this is the averaged propagation velocity, which is not precise enough or a different frequency should be used. To optimise the algorithm, further measurements will be done in the future. On the whole, a mobile test system is available and delivers the source location after tapping or knocking based on a holographic approach.

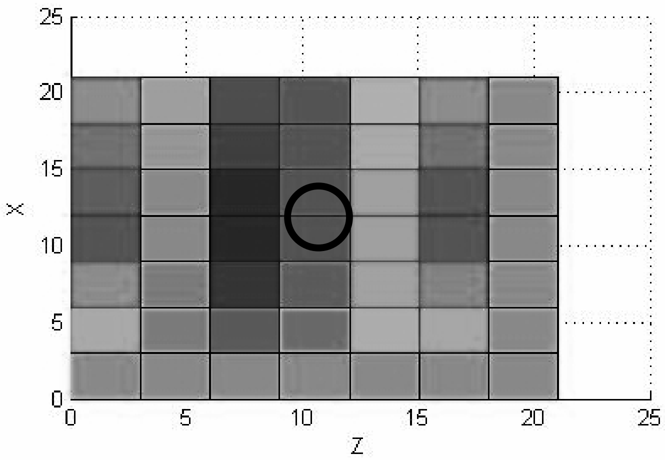

Figure 4. Result of localisation for frequency of 600Hz and circle indicates source position

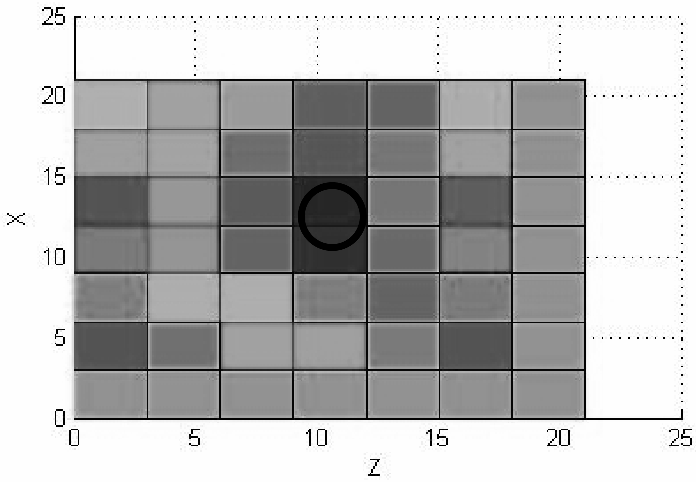

Figure 5. Result of localisation for frequency of 1600Hz and circle indicates source position

5. Prospectus

Experiments and mathematical simulations of Acoustic Holography in-solids have been conducted. The Rayleigh-Sommerfeld algorithm was developed for reconstruction of acoustic holographic images. At the moment, the source can be detected for certain frequencies, but methods to improve the reliability of localisation with acoustic holography are still under investigation. In future, the development of those enhancements will involve in new algorithms, the use of different types of transducers and searching for their best geometrical arrangement. Also the active method will be studied, where the media is stimulated by a continuous acoustic energy source.

6. Innovative Products

During evolution of mankind, tools and applications have become more important and complex. Therefore, control about this complex instruments developed by humans is going to be more difficult and essential, so that it is tried to use new kinds of interfaces. Principally, models, methods and proceedings have to be invented, with what humans are able to communicate with machines, what leads to the research and results of the TAI-CHI project.

In this article, a new approach for acoustic source localisation with direct measurements on solid objects is presented. State of the art methods like time delay of arrival according to propagation velocity and time reversal of the recorded signal are also applied, but sometimes they cannot be used to detect different source positions concurrently. The results of this article show that there is an alternative source localising procedure for solid objects which is capable of detecting more than one source simultaneous. This acoustic holography in solids will be implemented as well as the other methodologies into a prototype working as a Computer-Human Interface, where the sense of touch transmits information to machines. It allows each user to communicate freely with a computer, or an interactive system.

Obviously, the possibilities for acoustic interactive interfaces are unlimited. Starting from application scenarios like low cost desktop keyboards and consumer keypads, where no more switches are needed to an "invisible mouse", where the user moves his fingers directly on the surface of the table. Moreover, a device-free electronic whiteboard and pointing system by use of conventional pens or fingers and large scale interactive screens for academic presentations or educational purposes could be built. Other suitable products for this innovative interface are an interactive window in shops or public services and also for visitors to museums, information centres and exhibitions; not to mention part of an interactive environment of Virtual Reality. Skins for robots could be equipped with such touch interfaces what leads to sensitive surfaces in multi-transducer settings. On the whole, there exists a broad range of applications for a tangible acoustic interface.

Acknowledgement

This work was financed by the European FP6 IST Project "Tangible Acoustic Interfaces for Computer-Human Interaction (TAI-CHI)". The support of the European Commission is gratefully acknowledged.

References

Gabor, D., "A new microscopic principle", Nature, Vol. 161, 1948, pp 777-778.

Maynard, J., Williams, E., Lee Y. Nearfield acoustic holography: I. Theory of generalized holography and the development of NAH. J. Acoust. Soc. Am., 78, 4, 1985, 1395-1413.

Reference to MIT Museum, "Eye on holography", http://www.mit.edu/~sdh/holography/eoh/index.html/, 2002.

Reference to TAI-CHI homepage. http://www.taichi.cf.ac.uk/, 2004.

Rolshofen, W., Dietz, P., Schäfer, P., "TAI-CHI: Tangible Acoustic Interfaces for Computer-Human Interaction", DAGA'05, München, 2005.

*Rolshofen, W., Yang, M., Wang, Z., "Acoustic Holography in-Solids for Computer-Human Interaction", I*PROMS Virtual Conference, Cardiff, 2005.*

Roye, W., "Beitrag zur Weiterentwicklung der akustischen Holografie beim Einsatz in der Materialprüfung", VDI-Verlag, Reihe 5: Grund- und Werkstoffe, Nr. 117, 1987.

Williams, E., "Fourier Acoustics- Sound Radiation and Nearfield Acoustic Holography", Academic Press, 1999

Wolfgang Rolshofen
PhD-Student
Technical University of Clausthal, Institute for Mechanical Engineering
Robert-Koch-Strasse 32, 38678 Clausthal-Zellerfeld, Germany
Tel.: +49 (0) 5323 72-2158
Fax.: +49 (0) 5323 72-3501
Email: rolshofen@imw.tu-clausthal.de
URL: http://www.imw.tu-clausthal.de