Tangible Acoustic Interfaces and their Applications for the Design of New Musical Instruments

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ABSTRACT
Tangible Acoustic Interfaces (TAI) rely on various acoustic-sensing technologies, such as sound source location and acoustic imaging, to detect the position of contact of users interacting with the surface of solid materials. With their ability to transform almost any physical objects, flat or curved surfaces and walls into interactive interfaces, acoustic sensing technologies show a promising way to bring the sense of touch into the realm of computer interaction. Because music making has been closely related to this sense during centuries, an application of particular interest is the use of TAI's for the design of new musical instruments that matches the physicality and expressiveness of classical instruments. This paper gives an overview of the various acoustic-sensing technologies involved in the realisation of TAI's and develops on the motivation underlying their use for the design of new musical instruments.

Keywords
Tangible interfaces, new musical instruments design.

1. INTRODUCTION
In the context of the research on interfaces for Human Computer Interaction (HCI), one class of signals that has been considered with less attention is the acoustic vibration produced by the tactile interaction with objects, or by the contact between objects. The interest in such signals for the design of Tangible Interfaces is, however, very strong, as they carry a large amount of information about the interaction. One aspect is the possibility to locate the point of contact on an object. Previous works have explored this direction, and potential applications have been demonstrated for building large-scale interactive displays [1], extending gaming experience [2], and for creating new musical interfaces [3, 4].

Beside the location of the point of contact on the interface, further information about the nature of the interaction can be extracted from the resulting acoustic vibration, leading to new possibilities in terms of semantic and expressive content of the control process. A relevant musical application has been investigated recently, with the analysis of the sound produced by pebbles manipulated by hand [5]. However, a global approach to tangible interaction using acoustic technologies had yet to be investigated. This specific area of research is currently addressed in depth by the European project IST-507882 TAI-CHI (Tangible Acoustic Interfaces for Computer-Human Interaction) [6]. The final goal of the project is to define a wide and versatile "vocabulary" of interaction modes with tangible interfaces, involving gesture analysis and interpretation, which can be used for a variety of control purposes. What we present in this paper are the initial results of the TAI-CHI project, in the context of detection and classification of tactile interactions with tangible interfaces, and their application for the design of new musical instrument.

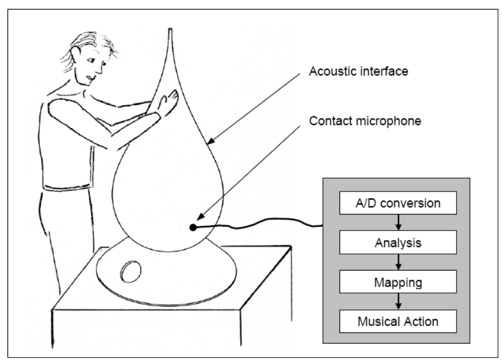

Figure 1. The original concept of TAI as musical interface.

Various methods for the detection and characterization of interactions can be considered. One example is given by the Time Reversal Process [7], based on the comparison and identification of the interaction signal with respect to a pre-recorded (learning phase) set of interaction signals. Another possibility is given by the Time Delay of Arrival (TDOA) estimation, based on the analysis and comparison of signals detected by a number of sensors arranged in an array [8]. Yet another possibility is brought by Acoustic Holography, a method for measuring a sound field using a microphone array [9, 10].

The following section will give an overview of the various technology approaches for the realization of TAI's. Section 3 will develop on the motivation underlying their use for the design of new musical instruments, including design aspects and mapping issues, and section 4 will report on the implementation of TAI's.

2. TECHNOLOGY OVERVIEW

2.1 Basic Principle

Any physical contact with a solid object or a surface (wall, table, etc.) is modifying its acoustic pattern by the way acoustic energy is distributed in the object and on its surfaces. Such perturbation of the acoustic pattern can be caused in two ways. First, by the acoustic vibration generated at the points of contact when tapping or moving a finger on the surface of the object (passive method). Second, by the acoustic energy that is absorbed at the points of contact (proportional to contact pressure) when the object is activated with ultrasound (active method). As acoustic vibration propagates well in most materials, this means that the information about the interaction can be conveyed to a remote location, using the structure of the object itself as a transmission channel and suppressing the need for any overlay or any other intrusive device over the area one wishes to make sensitive.

Generally, the TAI technologies are determining the geometric position of the acoustic sources (or sinks), which correspond to the points of contact on an object. Moreover, the additional information about the nature of the sound can bring extended control capabilities, as well as helping to eliminate false triggering due to ambient noise, or to operate selective tracking (for instance, a surface might be sensitive to the contact of a pen but not to a finger). It will thus be possible to determine *how* and *where* an object is touched or manipulated, providing a complete description of the interaction. The following subsections give an overview of the various technology approaches for detecting the contact position, that is, to locate where the object is touched.

2.2 Time Reversal

Time reversal in acoustics is a very efficient solution to focus sound back to its source in a wide range of material including reverberating media [7]. It is based on the principle that the impulse response in a chaotic cavity is unique for a given source location. The method that is employed here is a particular case of the Time Reversal technique and consists in detecting the acoustic waves in solid objects generated by a simple human touch. The detection is a two steps process. The first one is the acquisition of the impulse response: a short pulse is emitted by tapping on the surface of the object, which propagates toward the solid cavity and reflects inside. The echoes are collected by a contact transducer working as a receiver. The duration of the response depends on the absorption of the material and on the energy radiation property of the cavity. In the second step, the information related to the source location is extracted from a virtual time reversal experiment in the computer. The number of possible touch locations at the surface of objects is directly related to the mean wavelength of the detected acoustic wave.

2.3 Time Delay of Arrival (TDOA)

TDOA-based locators are all based on a two-step procedure applied on a set of spatially separated microphones. Time delay estimation of the source signals is first performed on pairs of distant sensors. This information is then used for constructing hyperbolic curves that describe for each couple of sensors (the foci of the hyperbola) the location of all points that correspond to the estimated delay. The curves drawn for the different pairs of sensors are then intersected in order to identify the source location.

This constitutes the very simple abstract and geometrical approach to the problem. However, a number of physical phenomena has to be considered in order to make the method reliable. Obviously, the performance of TDOA-based solutions depends very critically on the accuracy and the robustness of the time delay estimation (TDE). One can identify three major problems for TDOA methods for the in-solid case: background noise, reflections (multiple sound propagation paths) and, especially, dispersion. The most crucial problem of in-solid localization is given by the phase velocity dispersion occurring with in-solid wave propagation. This makes the estimation of TDOA's a complex task and the TAI-CHI project is investigating different solutions to override this problem [11].

2.4 Acoustic Holography

Methods for locating and visualising acoustic sources and intensity patterns are well developed for in-air applications. They are usually referred to as "Acoustic Holography" [9, 10]. Any sound field descriptor, such as sound pressure, sound intensity or particle velocity, can be calculated as a function of position and time. Results are typically displayed as animated maps to illustrate how a specific property changes as a function of time. Acoustic holography is sometimes referred to as an "acoustic camera" [12] because it allows an image of the sound sources to be visualized, in a similar way that an IR camera allows one to see sources of heat. The great innovation brought by the TAI-CHI project is to further develop Acoustic Holography for in-solid wave propagation. This means that measurements are executed directly on the object itself, using surface wave transmission. In this case, the reconstruction of acoustic patterns is only desired for a plan, so recording of acoustic waves need only to be taken along a line, using a mono-dimensional microphone array [13].

3. MUSICAL APPLICATIONS

Tangible Acoustic Interfaces lead to a very large number of applications in the field of Human-Computer Interaction. As already mentioned, they were originally conceived as new interfaces for musical expression [3]. This section explains the reasons that motivated their development in the context of musical applications and in particular for the design of new musical instruments.

3.1 The Model of Classical Instruments

Classical musical instruments are characterized by the fact that the performer interacts closely and most of the time directly with the source vibration (ex guitar, violin, etc). This is due to the symbiotic nature of the interface, which features a close integration of sound generation and control, and results in highly expressive capabilities. However, with the development of computer music and new interfaces for musical expression (NIME), we have observed a separation of the musical instruments into two separate interfaces:

- The gesture controller (movement-sensing device)
- The sound generator (usually the computer)

Therefore, the main goal of using TAI technologies for musical applications is to re-unify the sound generation and the control over the sound in the same interface. In other words, the goal is to use the acoustic waves generated by the interaction with an object as a sound source and to employ, at the same time, the same acoustic vibrations to extract control information for processing the sound by means of a computer. This way, it is possible to keep the original essence of classical instruments, but with new gestural interactions and extended control capabilities.

3.2 Extended Control

Compared to classical musical instruments, TAI based instruments offer two kinds of controls over the sound:

- The control over the generation of the sound (the way the vibration is produced, by tapping, rubbing, scratching, etc).

- The control over the simultaneous processing of the sound (by extracting control parameter from the above vibration)

To be complete, the latter require not only a localization of the interaction but also a refined characterization and interpretation of the interaction itself, based on pattern recognition techniques and gesture interpretation. Thanks to this, one could aim to recover a clear perceptual mapping similar to that of traditional instruments, i.e. to recover a clear correspondence between a physical gesture and the sound response produced by it. In a wider perspective, this approach will allow a tremendous expansion of the gesture scope and an unlimited freedom in the definition of movements that can communicate expressive details.

3.3 Instrument Design

A key aspect of TAI technologies is that they are not delivering a specific interface but a mean to transform a large variety of objects into interactive interfaces. For this reason, the final application will not be a specific NIME but rather an experimental kit, which enables people to transform almost anything into a musical instrument, giving a new freedom in the design of new musical interfaces. Objects of any form, shape and dimension can become an interface, as illustrated in figure 2.

Figure 2. Two design examples for TAI instruments.

Moreover, a new expressive dimension for musical instrument is introduced by the possibility to communicate a message not only with the sound, but also with the symbolic nature of the object that is chosen for the interface. In that sense, the creative dimension for the design of TAI based musical instruments is getting close to the art of sculpting and plastic art, in general.

3.4 Mapping

As mentioned before, in addition to the information about the position of contact on the object-interface, sound analysis allows extracting high-level parameter for extended control and interaction. The following table gives an overview of the parameters that can be used to control further sound processing.

Table 1. Control parameters and corresponding technologies.

Parameter	Value	Technology
Position	[x, y]	TDOA / Acoustic Holography
Position	Point index	Time Reversal
Pressure	[z]	Active Acoustic Holography
Volume	[v]	Amplitude follower
Action Type	Tapping, Scratching, Rubbing, etc	Pattern Recognition
Contact Type	Hard / Soft	Spectrum Analysis

Using the [x, y] information about the position, for instance, it is possible to draw a certain number of zones on the interface and assign them MIDI events, such as Note numbers and continuous controllers. The diagram in figure 3 shows an example of interface with various zones drawn on a flat object.

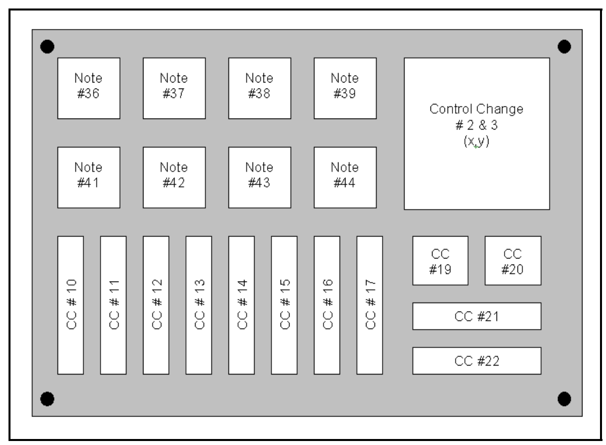

Figure 3. Mapping example with a flat object. Zones are drawn on the surface and assigned to MIDI Note # and Continuous Controlers.

4. IMPLEMENTATION

The following sub-sections give a summary of the experimental setups and results for the various technologies. Originally implemented on separate platforms, the algorithms are progressively ported on the EyesWeb software platform [14].

4.1 Time Reversal

The method has been successfully tested in various situations and with various objects. The example shown in figure 4 consists of a single piezo transducer attached to a blackboard and connected to the microphone input of a laptop. A grid of 9x6 points spaced of 4cm is drawn on a piece of paper fixed to the board. The red dot on the computer screen corresponds to the detected point.

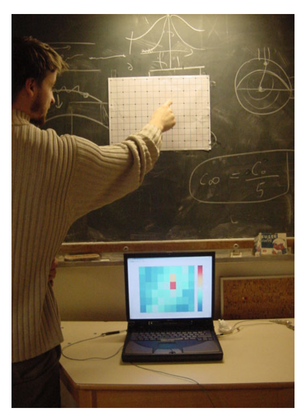

Figure 4. Touch detection experiment with Time Reversal.

4.2 TDOA

At present the investigation has been limited to the simple case of flat surfaces. Two kinds of materials were tested, glass and plexiglass, i.e. isotropous materials. The tables used were of three sizes, 130x100 cm2, 70x100 cm2 and 50x50 cm2, homogeneous with no discontinuities. The measurable criteria of the proposed technical approaches are in terms of spatial resolution of localization. Currently, the obtained resolution is of less than +/- 1 cm on a surface of about 15x15 cm2.

4.3 Acoustic Holography

In different series of tests, theory and algorithm of Acoustic Holography were applied. The investigated objects were a metal-plate, a board of wood and a glass-ceramic hob with different dimensions. Acoustic signals were generated with an impulse-hammer (figure 5). The used sensors were ICP accelerometers of PCB and the recording of the measured signal was done with an OROS signal analyzer. Finally, the measurement data processing for the localization was computed with a MATLAB script, where the Rayleigh-Sommerfeld algorithm was evaluated [13].

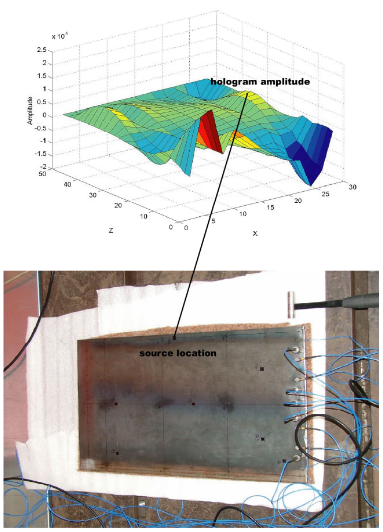

Figure 5. Measurement on a metal-plate and associated amplitude distribution.

5. CONCLUSION

One truly exciting idea about TAI technology is the possibility of transforming almost any object into an interactive interface. No extra devices are needed for the interface; only inexpensive piezo contact sensors and a few audio inputs for the computer are sufficient. Building low-cost, custom interfaces which offer a high degree of expressiveness is the real challenge of TAI controllers. This opens the door for a vast area of exploration. From small resonant objects to big structures, the potential to invent original interfaces is unlimited. In addition, the sound of the interface can be used not only to control other processes but also as a natural source for further manipulation, live sampling and processing. This gives this kind of NIME an even larger scope of creative development. Definitely oriented for further growth in the age of advanced technology, TAI based musical instruments bring back the historical unity of traditional instruments with the well-integrated duality of musical control and sound generation.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] J. A. Paradiso, C. K. Leo, N. Checka, K. Hsiao, "Passive Acoustic Sensing for Tracking Knocks Atop Large Interactive Displays". In *Proceedings of the 2002 IEEE International Conference on Sensors*, Volume 1, Orlando, Florida, June 11-14, 2002, pp. 521-527.

[2] H. Ishii, C. Wisneski, J. Orbanes, B. Chun, and J. Paradiso, "PingPongPlus: Design of an Athletic-Tangible Interface for Computer-Supported Cooperative Play". *International Conference on Human Factors in Computing Systems*, CHI99, Pittsburgh, Pennsylvania USA, 15-20 May 1999.

[3] A. Crevoisier, "Movement and Music, from traditional instruments to hyper-instruments". Dissertation, Master degree in Digital Art, University Pompeu Fabra, Barcelona, Spain, (2001).

[4] A. Crevoisier, P. Polotti, "A New Musical Interface Using Acoustic Tap Tracking". MOSART Workshop on Current Research Directions in Computer Music. Barcelona, (Nov 15-16-17, 2001). http://www.iua.upf.es/mtg/mosart/papers/p26.pdf

[5] S. O'Modhrain, G. Essl, "PebbleBox and CrumbleBag: Tactile Interfaces for Granular Synthesis". *Proceedings of NIME'04*, Hamamatsu, Japan August 2004.

[6] http://www.taichi.cf.ac.uk/

[7] Ing R. K., Catheline S., Quieffin N. and Fink M. "Dynamic focusing using a unique transducer and time reversal process". *Proceeding of the 8th International Congress on Sound and Vibration*, 119-126 (2001)

[8] Rinford H. J.: "Acoustic Emission Source Location in Theory and Practice". Brüel and Kjær Technical Review, Nærum Offset, Denmark, (1980).

[9] "Nearfield Acoustic Holography (NAH) I - Theory of Generalised Holography and the Development of NAH", by JD Maynard, E.G. Williams and Y. Lee.

[10] "Nearfield Acoustic Holography (NAH) II - Holographic Reconstruction Algorithms and Computer Implementation", by W.A. Veronesi and J.D. Maynard.

[11] P. Polotti, M. Sampietro, A. Sarti, S. Tubaro, A. Crevoisier, "Acoustic Localization of Tactile Interaction for the Development of Novel Tangible Interfaces". *Submitted. to the 8th Int. Conference on Digital Audio Effects,* DAFX-05, Madrid, Spain, September 20-22, 2005.

[12] Acoustic Camera: http://www.acoustic-camera.com http://www.hta-bi.bfh.ch/CPG/demos/camera.html

[13] Düsing C., Rolshofen W., "Berührbare akustische Benutzerschnittstellen". IMW - Institutsmitteilung Nr. 29, pp. 63-66, 2004.

[14] www.eyesweb.org