AcouMotion – An Interactive Sonification System for Acoustic Motion Control

Thomas Hermann[1], Oliver Höner[2], and Helge Ritter[1]

[1] Neuroinformatics Group,
Faculty of Technology, Bielefeld University, D-33501 Bielefeld, Germany
[2] Institute of Sport Science, University of Mainz, D-55099 Mainz, Germany

Abstract. This paper introduces *AcouMotion* as a new hard-/software system for combining human body motion, tangible interfaces and sonification to a closed-loop human computer interface that allows non-visual motor control by using sonification (non-speech auditory displays) as major feedback channel. AcouMotion's main components are (*i*) a sensor device for measuring motion parameters (*ii*) a computer simulation to represent the dynamical evolution of a model world, and (*iii*) a sonification engine which generates an auditory representation of objects and any interactions in the model world. The intended applications of AcouMotion range from new kinds of sport games that can be played without visual displays and therefore may be particularly interesting for people with visual impairment to further applications in data mining, physiotherapy and cognitive research. The first application of AcouMotion presented in this paper is *Blindminton*, a sport game similar to Badminton which is particularly adapted to the abilities of people with visual impairment. We describe our current system and its state of development, and we present first sound examples for interactive sonification using an early prototype. Finally, we discuss some interesting research directions based on the fact that AcouMotion binds auditory stimuli and body motion, and thus can represent a counterpart to the Eye-tracker device that exploits the binding of visual stimuli and eye-movement in cognitive research.

1 Introduction

Auditory information plays an important role for directing and coordinating human activity [1]. Almost every human activity, like closing a door or putting down a cup on the table, every foot step and almost any physical contact is connected with an acoustic feedback. This provides us with a variety of information about certain details of the interactants, e.g. their material, stiffness, energy, texture. In addition to such interaction sounds there are environmental sounds that give us useful hints on another level: they direct our attention (e.g. to an approaching car, or a mobile phone), or increase our awareness (think of the symphony of sounds in a wood from bird songs to the wind in the leaves).

Maybe it is because we interpret and use these informative signals so routinely and completely effortless that auditory information was not sufficiently appreciated for a long time. This may be one reason why our culture developed in a

S. Gibet, N. Courty, and J.-F. Kamp (Eds.): GW 2005, LNAI 3881, pp. 312–323, 2006.

rather visual-centered way. Particularly interaction with computer technology is still very eye-oriented. Over the last decade, sonification started to offer alternative, auditory displays which aim at addressing our auditory skills for analyzing data, particularly high-dimensional data [2]. These techniques now become more and more interactive, and they enable the user to navigate for instance data under analysis while perceiving in real-time an auditory representation [3].

In search for more ecological (i.e. natural and intuitive) interactions with auditory data displays, soon other controllers and interfaces than the keyboard and mouse came into view. When interacting with the environment, we usually employ our hands and arms, which are both very versatile, and which offer multi-dimensional controls. A combination of body motion and sound is not only interesting from the perspective of sonification, e.g. in musical performance it allows to bind dance and musical performance together.

This paper presents the new system *AcouMotion* that provides a link between motor activity and auditory feedback through sonification. *AcouMotion* is a hard-/software system that consists of a tangible sensor device, a dynamic model implemented in a computer simulation and a sonification engine. Interactions (resp. actions) with the interface object are mapped to manipulations of objects in the dynamic model. Reactions in the model world are displayed by sonification as the only feedback modality.

AcouMotion offers various applications, and we give in this paper a sketch of the possibilities plus a more detailed description of our first implemented application: using AcouMotion, we develop a new sport game for users with visual impairment that we call *'Blindminton'*, an adapted version of Badminton. The paper provides an overview of interactive sonification in Sec. 2, followed by the presentation of the AcouMotion system in Sec. 3, the basis for Blindminton (see Sec. 4). In the end in Sec. 5, we discuss different research possibilities of AcouMotion in diverse disciplines, with a focus on applications in Sports Science, Data Mining and cognitive research.

2 Interactive Sonification

Sonification is the use of non-speech audio for the representation of information [2]. Auditory displays, opposed to visual displays are inherently dynamic so that the information is in principle offered in the flow of time. While we can navigate visual displays actively by directing the visual focus, it seems that we are almost incapable of doing the equivalent in sound, apart from perhaps to focus our auditory attention on certain aspects of a perceived sound (e.g. to listen to the clarinets in a piece of music). However, this is the point where interaction comes into play. Usually, our environment is silent in the absence of excitation, and we ourselves cause excitation by interacting with the world. Due to the invariance of this principle evolution has optimized the human perceptual apparatus to cope with such multi-modal closed interaction loops. Inclusion of interaction in sonification is therefore a plausible step to better fit our sensomotor skills to the use of auditory display systems. While interactive sonification mainly addresses the issue of investigating data by using interactive navigation controls, we here suggest an interface that uses also the data measured by a sensor device as source of sonification, and so provide acoustic motion feedback.

There are various techniques of sonification like Earcons, Auditory Icons, or the more complex techniques Parameter Mapping and Model-based Sonification [2, 4]. **Parameter Mapping Sonification** is a frequently used strategy to transform data streams $\{\mathbf{x}_i\}_i$ to acoustic streams [5]. Usually a mapping function $\mathbf{y} = f(\mathbf{x}) = \sigma(\mathbf{A}\mathbf{x})$ is applied to compute the acoustic attributes vector $\mathbf{y}$, frequently using a linear transformation A and a nonlinear distortion function σ. The components of $\mathbf{y}$ are sound synthesis parameters like for instance frequencies, amplitude, modulation indices.

Model-Based Sonification. (MBS) involves a dynamic model to mediate between the data and the sound [4]. Instead of controlling a sound synthesis engine, the data determines the setup of a dynamic system whose temporal evolution is the only process that generates sound (i.e. the sonification). The main advantages compared to Parameter Mapping are that MBS supports a generic design, tightly integrates interaction, and automatically generates acoustic relations that are intuitively understood (like the more a system is excited, the louder it typically sounds).

3 AcouMotion

Applications of the system *AcouMotion* use a mix of the sonification techniques mentioned above, e.g. Auditory Icons for displaying discrete events, Parameter Mapping for analogous data display and, for instance, Model-based Sonification for more complex data representations through audio.

The core idea behind AcouMotion is to employ sonification to create a new channel of proprioception allowing to perceptually relate body motion to virtual objects in a virtual space whose properties can be designed to support a wide range of different applications. AcouMotion connects three system components to implement this idea: (*i*) a *tangible sensor device* providing motion-related information, (*ii*) a *computer simulation model* formalizing the coupling between body motion (reflected in the sensory data provided by the tangible device) and the object dynamics in the virtual space, and (*iii*) a *sonification engine* for the perceptual rendering of the joint dynamics of body and modeled object states.

Body motion sonification in general bears the potential that gestural expressions (e.g. emotions) carry over to rhythmic and dynamic sound properties so that AcouMotion can be used for categorizing and monitoring gestural behavior. As bio-feedback system it allows the user to monitor his own activities on the background of a known 'auditory action template' and thus to evaluate differences in gesture execution which is interesting for motor learning and control in sports, but also for actors or choreography training.

From an application perspective, AcouMotion's underlying enhancement of proprioception for monitoring behavior in flexibly designable VR models of environments can also be used to analyze and support *training in sports*, to offer novel ways of exploration and navigation in *interactive data mining*, to induce and stabilize therapeutic movement patterns in *physiotherapy*, and to offer new avenues for *investigating cognitive processes*.

In the following, we will illustrate only one research direction of our approach with a specific application example taken from the domain of *sport games* (further applications are pointed out in Sec. 5). In this example, the tangible controller will be a small handheld device, moved in a racket-like manner providing sensor signals allowing to drive a "virtual racket" in the model space. The model space will additionally contain a virtual game arena consisting of a floor, a demarcated field, a ball and reflecting walls. The sonification engine will create a real-time soundscape that allows to infer the distance, the position and the velocity of the virtual ball relative to the racket. Thereby, it will provide the player with non-visual proprioception how to perform a successful hit back of the ball to continue the game.

In this example the body motion is functional in the sense that only the "physical" contact of a virtual ball and virtual racket are relevant for playing the game. It is not determined how the player achieves this goal. Gestures, as a more indirect means of communication may be implemented in further game applications as AcouMotion is developed as a very general platform (e.g. a game "Gesture Imitation" where one blindfolded person challenges the opponent by performing a body gesture which results in a sonification, followed by the other player who may have 3 trials to reproduce the body gesture purely by trying to reproduce the sound).

3.1 Sensor Devices

In AcouMotion a variety of sensor devices can be used. They all have in common that they deliver real-time data about the user's physical activity. For a game like Blindminton, the position of one hand in high spatio-temporal resolution would be required. For other applications of AcouMotion, one might need only accelerations, or whole body movements, or force measurements.

As a general framework, we propose a *tangible sensor device* for AcouMotion. Users are familiar and highly skilled in using tools from everyday experience or many sport games, while purely gestural interactions are rare[1]. As a professional solution for our sensor device we use the Lukotronic motion capture system[2], which is able to track the 3D-position of a set of markers with a frame rate of 1200 Hz. The Lukotronic system consists of a set of fixed IR-cameras and flashing IR-markers. Using four markers mounted on a tangible device like a small racket allows us measuring the full 6D position/orientation of the racket. Furthermore, we can compute the velocities and accelerations at high accuracy from successive frames.

[1] However, the Theremin (see www.thereminworld.com/learn.asp) is a music instrument played via gestural interaction alone, and there are many motion forms like Tai-Chi or dance. Thus even cameras are suited sensors to be used in AcouMotion.

[2] http://www.lukotronik.com

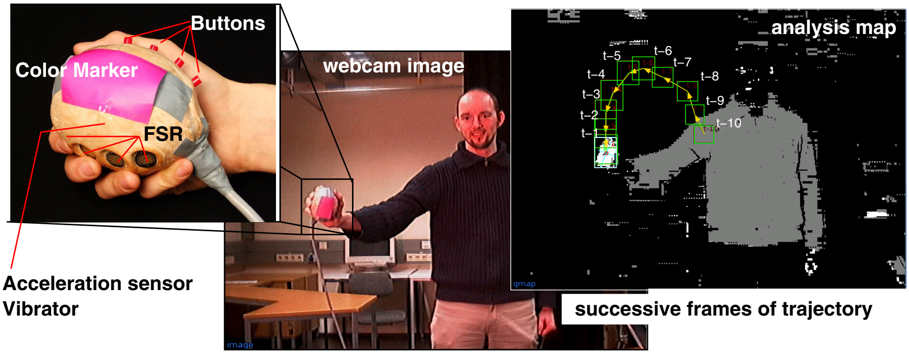

Fig. 1. Webcam-based position estimates. The figure shows a player using the interface ball, and the webcam image including analysis results.

In addition, we search for a less expensive solution for AcouMotion. Our first experimental prototype is a haptic controller equipped with two 2D accelerometers and 5 force sensitive resistors to provide interactions like movement, rotation, shaking, squeezing, etc [6]. The interface is shown in Figure 1. A cable-free version using Bluetooth will free us from actual mobility limits and is a next target for development.

The frame rate is a crucial parameter in real-time interactions, and we currently obtain and process sensor data at 100 Hz, which is sufficiently high to create the illusion of latency-free control. However, the integration of accelerometer data to spatial coordinates is difficult and we require an independent means to eliminate drifts. Currently we solve this by a computer-vision based approach as shown in Fig. 1. By using a simple webcam, we are able to obtain 2D-coordinates of the ball at 25 Hz, and using a fixed sized visual marker, we can compute a rough estimate of the distance. We plan to fuse these estimates with predictions from the sensor data integration. Although the prototype of the haptic controller suffers from relatively low frame rates at this time, it is a valuable complement for the Lukotronic system in the Blindminton application. In combining the Lukotronic system and our haptic control device we are able to measure the position of the player's hand with high spatio-temporal solution and give also a feedback for crucial game events, in particular the hit of the ball. Using such additional haptic information augments the feeling of having control over the game. This is an essential condition for motivating flow-experiences during the game. Integrating haptic information is therefore believed as an important condition for people's motivation playing the game.

3.2 Computer Simulation

A dynamic model is the basis for representing processes and interactions in AcouMotion. The model represents the internal state of the AcouMotion system, and evolves according to its own "physical laws". In applications like the sport game like Blindminton, we suggest to use laws we are familiar with from everyday experience (e.g. the ball flies through a 3-dimensional space influenced by gravitational force and aerodynamic resistance)[3].

To start we use a physical model in a 3D model space with a limited number of objects represented by their coordinates, velocities and orientations. For instance in a one-player version of Blindminton, the objects are the racket, the ball, and a set of planes and walls to model the game field and floor. In our current prototype, the ball is described by a sphere or radius r, mass m and its state vector $(\mathbf{x}_b[n], \mathbf{v}_b[n])$. In later versions it will also include the property of angular momentum. In a similar way, the racket is modeled by a cuboid. It is special in the way that its coordinate and orientation is strictly determined by the external sensor data. In contrast, the ball is free and only bound to follow the motion equations

$$m\ddot{\mathbf{x}} + R\dot{\mathbf{x}} + \nabla_x V(\mathbf{x}) = 0 \quad \text{with} \quad V(\mathbf{x}) = g\hat{z} \tag{1}$$

The state of the model is updated at a constant rate ΔT by using numerical integration. For instance, the ball is updated using

$$\begin{aligned}
\mathbf{x}[n+1] &= \mathbf{x}[n] + \mathbf{v}[n+1]\Delta T \\
\mathbf{v}[n+1] &= \alpha\mathbf{v}[n] + \mathbf{a}[n+1]\Delta T \\
\mathbf{a}[n+1] &= -\frac{1}{m}\nabla V(\mathbf{x}[n])
\end{aligned}$$

In addition to these update steps, the simulation needs to check at every time step whether there are interactions with objects (e.g. the ball and the virtual racket), and respond with update in this situation, like an elastic impact. Such event-based information is highly relevant for the auditory display.

While real-world settings have to operate with the existing physical laws, the computer simulation enables us to control any circumstances in principal, for instance the viscosity of the air. This might cause a retardation of the ball due to increasing aerodynamic resistance, etc. Thus, we can control the complexity and difficulty of the task in detail to create a challenging game.

3.3 Sonification Engine

Sonification bridges the gap between the only virtually existing model state and the auditory perception of the user. The sonification shall provide ample information to enable the user to operate whatever interactive activity is needed in the respective application. This could be the successful hitting of the ball, but also navigation in complex data spaces in more abstract settings.

Sound offers extensive possibilities to incorporate detailed information about ongoing processes. The sonification engine itself is an algorithm which receives as input the state of the model, and creates as output either the sound directly or control messages to a synthesis engine.

[3] However, this falls in the hand of an application designer. For instance this model can be a sonification model so that interactions may be used to analyze high-dimensional data as described in Sec 5.

Practically we use Supercollider [7], an object oriented language similar to SmallTalk for the implementation of the model, and the Supercollider sound server for the computation of audio data. The sonification engine can be exchanged easily by other implementations in C++ or our graphical simulation environment Neo [8] since communication to the sound server is achieved via Open Sound Control (OSC).

Sensor device, computer simulation model and sonification engine are connected via OSC interfaces, allowing easy exchange of sensors, or distribution on different computers.

Basis elements of our auditory display are (*i*) *continuous sound streams* which convey information by the change of acoustic attribute (an example is a pulsed sound whose pulse rate represents distance to the player). (*ii*) *discrete sound events*, which are used to communicate discrete event (e.g. physical contact interactions in the model) (*iii*) *ambient elements* like sound effects, that influence the overall display.

4 Blindminton – A Sonification-Based Sport Game for Adapted Physical Activity

In this section we focus on our first application of AcouMotion, a new sport game called *Blindminton*. Blindminton is providing a test case for several applications focusing on the excellent auditory perception skills which are highly adapted for people with visual impairment due to their enhanced everyday use. It is an application of the transdisciplinary method of interactive sonification in the interdisciplinary research field of *Adapted Physical Activity (APA)*, a relatively new focus within physical education and kinesiology for people with deficiencies, disabilities, handicaps or special needs [9]. The sonification-based game Blindminton will be motivated from a brief analysis of sport games in general (Sec. 4.1), and games for people with visual impairment in particular (Sec. 4.2). We illustrate the progression of our started research project and then show the current status of the implementation (Sec. 4.3).

4.1 Perception and Action in Sport Games

People playing sport games have to deal with great demands on multi-modal perception for action control due to the extreme spatio-temporal constraints in the complex and dynamic environment of sport games. It is therefore a very important condition for top-performance to use effective strategies for information perception. As visual information is considered to be the most important information for action control in sport games, one of the major interests in cognitive research on anticipation and decision making in sport games is to analyze visual search strategies [10].

Despite the dominance of visual information there can be no doubt that other types of information are also important for top performance in sport games and you need a holistic, multi-modal perception for optimal action control. For instance, you cannot reach top performance in table tennis without receiving auditory information about the ball bouncing on the table.

The human multi-modal perception system is adaptive to the environmental demands. On the one hand, this fact is used in training concepts closing one information channel (e.g. 'Close your eyes!') to train other perception systems ('try to control the ball just with the tactile information of your feet!'). On the other hand, people with visual impairment are forced to adapt their information processing due to their missing visual information in everyday life. This motivates us to search for sport games reducing the requirements of visual information and increasing the importance from other information like sound. Thus we take a look for already existing games for people with visual impairment.

4.2 Sport Games for People with Visual Impairment

Sport games offer important experiences in body movement and body motion and are of crucial importance for the psychosocial development of people with visual impairment. As visual information is the leading afferent information for action control in sport games it is particularly difficult for these people to take part in sport games. But since these people also desire to get access to sport games, it is one of the most important tasks in the research field of APA to expand the boundaries of ordinary sport games and search for new opportunities or enabling techniques to facilitate their participation.

Until now, there are only very few sport games for people with visual impairment. One of them is the so called ball game Goalball which is very significant: Goalball was created especially for blind people and the only paralympic sport game for people with visual impairment for many years[4]. It was accompanied by the game 'football-5-a-side' in the recent paralympic games in Athens 2004. These sport games show impressively the adapted perceptual skills of sportsmen using non-visual information and proof the possibility to play sport (and even ball) games without any visual information.

Searching for further non-visual sport games, we use insights from three areas: Firstly, existing sport games like goalball are analyzed and their basic principles like the sounding ball are used to create new games. Secondly, we regard successful applications of interactive sonification in auditory computer games. Games like 'Super Tennis' can be played against the computer just using auditory information and are very popular, in particular for people with visual impairment[5]. Finally, we take virtual simulations of sport games into consideration. Games like 'Virtual Table Tennis'[6] are games consisting of virtual simulation. They can be played against the computer or via internet against another opponent within VR using a virtual ball.

We break new ground in using the method of interactive sonification [4] to present auditory information as the leading information for action regulation in

[4] see http://www.ibsa.es/eng/deportes/goalball/presentacion.htm
[5] see http://www.audiogames.com
[6] see http://www.vtt.fi/multimedia/camball/camball.html

sport games. This enables us to present auditory information in a more systematic way as in the existing sport games using natural sounds like the ringing of a bell inside the goalball. Auditory computer games already use interactive sonification and can be seen as challenging games, predestined for motivating flow experiences[11]. But from the perspective of APA computer games do not offer movement experiences promoting motor development like sport games.

AcouMotion integrates interactive sonification, movement experiences and virtual game simulations and goes beyond hitherto existing systems. The system provides a technical basis offering new auditory sport games that can be played just by using non-visual sonification-based information with real motor activity. In the following we present the game concept of our first application *Blindminton*.

4.3 Blindminton - The Game Concept

The lack of adapted sport games for people with visual impairment makes it necessary to provide these people with ample information enabling them to conduct a challenging sport game. We show how to realize this by using AcouMotion. To attack the ultimate challenge of a multi-player game for blind people, we decompose the problem in smaller steps. This allows to treat smaller problems, and to develop a series of highly promising research platforms.

Basically, Blindminton is a game where a (here virtual) ball is being hit by a racket until it comes to a rest. If a player places the ball into 'out', or fails to hit back the ball properly, the opponent gets a point. The winner of the game is the player who first reaches 15 points.

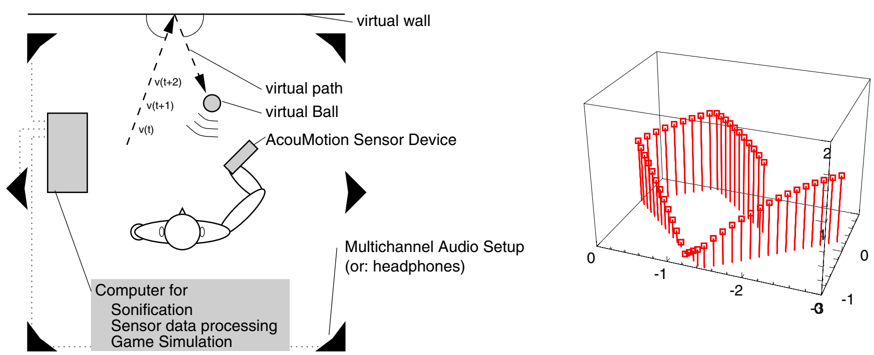

Fig. 2. Blindminton game setting. The plot shows a simulated ball trajectory with 4 impact events.

One-Player Blindminton. We start with a limited version of Blindminton where the opponent is replaced by a fixed wall, so that the task is being turned into the game of keeping the (virtual) ball in the game as long as possible. In this game we can increase the score for every wall contact, and have the opportunity to make the score dependent upon the ball speed at the wall. This introduces an element which engages the player to increase his activity to obtain better scores. Alternatively, other motivational elements can be introduced, like the task to touch every tile of the virtual wall. What tiles remain to be touched can be communicated by the wall contact sonification which delivers the information at what distance and direction the nearest unhit tile is located. The score would then be reciprocal to the time needed to hit a tile.

All components of AcouMotion are required for implementing this game. In particular the AcouMotion sensor device is able to deliver position and orientation of the racket. Orientation is crucial since the ball reflects from the racket (via input angle=output angle) and this is an essential control to conduct the game.

Two-player Blindminton. Is an extension towards team plays. A second motion sensor device is needed. With some extensions, the rules of classical Badminton can be taken. The sonification engine has to be extended so that the opponents activity (e.g. position) is displayed to each player. Communicative aspects must be respected (like that the sonification may not overly interfere with vocal communication between players). This is the intermediate step towards team games like a '3 vs. 3' Blindminton (played like Volleyball).

4.4 Auditory Information Design

In games like Blindminton there are different types of information-carrying variables, like

Continuous Variables: Ball position, ball relative position, distance to racket, ball velocity, ball angular momentum, racket position, racket orientation,

Discrete Events: Ball/racket contact, ball/floor contact (in/out field), ball/wall contact, player (resp. sensor) leaves field borders,

Pseudo-discrete Events: Using a division of space into zones: ball crosses a zone plane. Pseudo-discrete events create an auditory gestalt, for instance as a pulsed event chain so that information is conveyed not only through the event itself but its relation to other events.

The auditory display aims at delivering much more information in sound than obtainable in real-world interactions. For instance, a flying ball may contribute a level-modulated sound pattern with pulse rate increasing when the ball approaches the racket and 'effet' can become audible as well. A video of our current Blindminton game is available on our website[7].

5 Discussion: Towards Acoustic Body-Tracking

The paper has introduced the AcouMotion system and Blindminton as a first application. AcouMotion opens a range of applications and research directions.

[7] see http://www.techfak.uni-bielefeld.de/~thermann/projects/index.html

In **Sports Science**, AcouMotion plays a role to investigate for instance *motivational aspects*. Which informational factors (display richness, information latency, difficulty) make games motivating? Here the obtained information can be controlled via the sonification engine in full accuracy. Connected to this is the *analysis of motor laerning and training processes*: How do humans learn coordinated movements, and which factors can efficiently contribute to accelerate learning processes? For instance, it is argued that beginners learn faster if their task is simplified (e.g. by a larger racket). In Blindminton, we can not only control the virtual racket size dependent of the performance level, we can also control such variables continuously during the learning progress within the activity. Further on, AcouMotion has recently been used for testing players' reaction on spatially resolved sound cues. From a pilot study ([12]) we are optimistic to develop a useful performance test for paralympic game Goalball using AcouMotion. *Flow experience* is another important phenomenon observed in sports, but also in musical performance, etc [11]. It describes the dissolving of the person in his activity so that the mental focus becomes free to concentrate on higher levels (e.g. in playing music: from technical control to performance and emotional expression). The factors that potentially contribute to the emergence of flow can easily be examined with AcouMotion.

In the discipline of **Data Mining**, the challenging task is to understand structures in high-dimensional data. Interactive techniques can support the insight into data. Exploration and navigation tasks heavily rely on the perception-driven refinement of activity. Thus, AcouMotion may be applied to decrease the gap between abstract high-dimensional data spaces and human's natural interfaces, e.g. by using multi-modal exploration models that involve sonification. An impact on the degree of immersion, performance, reaction time, or a reduce of fatigue may be positive outcomes of applying AcouMotion in this domain.

In **Physiotherapy** we see the potential that AcouMotion can be a useful tool to induce therapeutically valuable movement patterns. To give only one example, consider a game where the tangible sensor device is used to catch virtual butterflies around your body. An additional sensor array attached to the user's back records motion parameters and directs the butterflies so that you activate your back in a therapeutically ergonomic way.

Cognitive Research. We believe that AcouMotion offers an interesting *analogy to eye tracking*: while the measurement of eye movements in response to visual events as a major 'window' into cognitive processes has become a widely established methodology, the analogous measurement of *body movements* in response to *auditory information* has so far been much less exploited. AcouMotion can fill this gap by providing a sound basis for studying this complementary link between modalities, complementing the dyadic eye-mind hypothesis of eye tracking research[13] with a triadic ear-mind-bodymotion hypothesis, stating that body motion responses to specific sound patterns can reveal information about the focus of ongoing cognitive processes. In this way, AcouMotion helps to answer research questions like: How are acoustic information from interactions processed and used to refine motor activity? How are emotional cues processed? Sound is an ideal carrier for emotional information, and emotion influences body gestures. How do these systems relate to each other?

In conclusion, we recommend AcouMotion as a new auspicious platform to enhance human-computer interaction and investigate the relation between human information processing and human action.

Acknowledgment

Parts of this project are granted by the Federal Institute of Sport Science (II A 1 - VF 070404/05-06). We also thank Christof Elbrechter and Till Bovermann for help with the vision system and Supercollider programming. We thank Arthur Steinmann for technical support.

References

1. T. Hermann and A. Hunt, "An introduction to interactive sonification," *IEEE Multimedia*, April-June 2005, vol. 12 no. 2, 20–24, IEEE.
2. G. Kramer, Ed., *Auditory Display - Sonification, Audification, and Auditory Interfaces*. Addison-Wesley, 1994.
3. A. Hunt and T. Hermann, Eds., *IEEE Multimedia, Special Issue Interactive Sonification*, IEEE, 04 2005.
4. T. Hermann, *Sonification for Exploratory Data Analysis*, Ph.D. thesis, Bielefeld University, Bielefeld, 2002.
5. C. Scaletti, "Sound synthesis algorithms for auditory data representations," in *Auditory Display*, G. Kramer, Ed. 1994, Addison-Wesley.
6. T. Hermann, J. Krause, and H. Ritter, "Real-time control of sonification models with an audio-haptic interface," in *Proc. of the Int. Conf. on Auditory Display*, R. Nakatsu and H. Kawahara, Eds. Int. Community for Auditory Display, 2002, pp. 82–86, Int. Community for Auditory Display.
7. J. McCartney, "Supercollider: a new real time synthesis language," in *Proc. ICMC '96*. Int. Comp. Music Assoc., 1996, http://www.audiosynth.com/icmc96paper.html.
8. H. Ritter, "The graphical simulation toolkit Neo/NST," `http://www.techfak.uni-bielefeld.de/ags/ni/projects/simulation_and_visual/neo/neo_e.html`, 2000.
9. G. Reid. and H. Stanish, "Professional and disciplinary status of adapted physical activity," *Adapted Physical Activity Quarterly*, vol. 20, pp. 213–229, 2003.
10. A.M. Williams, K. Davids, J.G. Williams, *Visual Perception and Action in Sport*, E & F. N. Spon., London, 1999.
11. M. Csikszentmihalyi, *Beyond boredem and anxiety*, Jossey-Bass, San Francisco, 1975.
12. O. Höner, T. Hermann, T. Prokein, *Entwicklung eines goalballspezifischen Leistungstests*, In S. Würth et al. (Eds.), Sport in Europa, p. 331, Hamburg: Feldhaus, 2005.
13. M.A. Just, P.A. Carpenter, *The psychology of reading and language comprehension*, Boston: Allyn & Bacon, 1987