Gesture-Controlled Interaction with Aesthetic Information Sonification

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ABSTRACT

Information representation in augmented and virtual reality systems, and social physical (building) spaces can enhance the efficacy of interacting with and assimilating abstract, non-visual data. Sonification is the process of automatically generated real time information representation. There is a gap in our implementation and knowledge of auditory display systems used to enhance interaction in virtual and augmented reality. This paper addresses that gap by examining methodologies for mapping socio-spatial data to spatialised sonification manipulated with gestural controllers. This is a system of interactive knowledge representation that completes the human integration loop, enabling the user to interact with and manipulate data using 3D spatial gesture and 3D auditory display. Benefits include 1) added immersion in an augmented or virtual reality interface; 2) auditory display avoids visual overload in visually-saturated processes such as designing, evacuation in emergencies, flying aircraft; computer gaming; and 3) bi-modal or auditory representation, due to its time-based character, facilitates cognition of complex information.

Keywords

Gesture controllers, spatial interaction, 3D auditory display, sonification, spatialisation.

1. BACKGROUND

Existing sonification falls into two categories: those sonifications that draw from remote information and those that use contextually localised information sources, for scientific (monitoring) purposes and artistic (creative) purposes.

Abstract, remotely-located data (stocks, Internet traffic, building life-cycle data, etc.) can be interacted with by gestural control that transforms or manipulates the data by altering the original data set. Gestural interaction in a sensate space (enabled by sensors such as pressure mats, infra-red sensors, proximity sensors, video tracking for capturing data) affects data and display in that space. Some examples of current (non-interactive) sonification are shown in Table 1.

Scientific sonification or visualisation of abstract data is intended to illuminate or augment our understanding of abstract (non-visual) data. There are contexts in which sonification is more helpful than visualisation: utilising the human auditory capacity for detecting subtle changes and comprehending dense data; and to avoid overload on visual senses, e.g. during surgery, anaesthesiology, and aircraft control, for navigation and emergency evacuation in low visibility conditions. Adding **interactivity** to auditory representation of information introduces a new degree of control and potential understanding. Clusters, patterns, recurrences and trends in data are easily recognised in auditory display.

Gestural computing aims to move away from desk-bound, restrictive computing environments and to move towards ubiquitous computing that is more integral to the building structure and space itself. Our environment becomes more reactive, responsive and the boundaries between architecture / computing or between working / mobility or entertainment / reality are blurred. Gestural control of auditory representation forms a link for understanding data in augmented reality systems.

Table 1. Examples of the wide variety of information that can be sonified for variously scientific or artistic purposes. The sonification process is usually passive, i.e. non-interactive.

Sonification author & title	Source data
Ciardi's *sMAX: A Multi-modal Toolkit* for Stock Market Data Sonification	sonifies data from stock market environments, in which large numbers of changing variables and temporally complex information must be monitored simultaneously [7; 18]
Janata and Childs *MarketBuzz*	sonification of real-time financial data, in which "auditory display is more effective and consistent for monitoring the movement of volatile market indices" [13]
Andrea Polli's *Atmospherics/Weather Works*	sonified meteorological data designed for museum installation/exhibition with the additional agenda of displaying narrative [20]
Garth Paine's *PLantA*	using a weather station to capture dynamic non-visual data measurements of wind velocity, direction, temperature and UV levels [19]
Hermann, Baier & Müller: *Polyrhythm in the Human Brain*	derived from EEG brain data [10]

2. AIM

This paper proposes a theoretical framework and an implementation model for gestural interaction with information sonification.

Sonification is the computational process of representing information using sounds. Representing information with sound

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can serve to elucidate patterns, behavioural trends, cliques, recurrences and reveal time-based transitions so that the information can be better understood. There is a gap between existing sonification methods and human interpretation. Current sonification (or ambient display) processes are often one-way (information to display), passive and non-interactive. While those interactive systems that currently exist permit interaction with the display but do not enable the user to transform the fundamental data. Gesture controllers for spatial interaction are used in music for manipulating sounds in **performance** and **real time composition**. (Gesture controllers measure non-tactile motions, using spatial gesture instead of clicks and mouse-movements for interaction, e.g. detecting acceleration, gyroscopic motion, direction sensors, proximity, flex). This framework bridges the gap between passive information representation and the ability to interact with, transform and manipulate the data by enabling gestural interaction with the information source. The feedback loop is completed when the users can affect change in the source data (Figure 1). The aim of this framework is to provide an interactive sonification that brings together compositional (musical) knowledge and information sonification in an aesthetic, culturally enriching informative display.

Sonification in this process translates socio-spatial information captured by sensors into aesthetic auditory display. Socio-spatial information is defined as attributes of motion in space (i.e. 3D position, velocity, proximity to particular objects and boundaries) and social behaviour (i.e. the number of people, level of activity, clustering, timing of events). Socio-spatial information reveals knowledge about the ways in which flows and activities occur in architectural and social spaces – the number of people, directional flow, times of peak activity, recurrences, locations where clusters convene. This is useful data for understanding the flow and life-cycle within a space. It is also socially reflexive information, pertinent to participants. Sonification of this information makes it accessible to the people who create it. The motivation behind involving people interactively with data sonification is to increase awareness of socio-spatial activity, to culturally endow users with the ability to shape, enrich and participate in their auditory environment. Interactive ambient display being suggested here is a form of **infotainment** – both useful and engaging. Participatory sound-scapes invite interaction and involvement. The idea behind aesthetic computing is contribute to informative contextualised contemporary sound installation in building spaces. It is a way in which to promote the richness of **cultural integration** of arts, especially informative and contemporary sound in our daily environment. Many (purely informative) computing visualisation and sonification processes do not emphasise the value of **aesthetic** display. This framework provides a practical implementation of socially-shaped sonification while bridging a technology gap that enables wireless gestural manipulation of auditory display.

2.1 Social Contexts for Responsive Environments

The following example developed in the author's sensate lab (Figures 4 & 5) demonstrates the way in which socio-spatial behaviours are mapped onto a computational process of sonification and visualisation. Beilharz, Vande Moere and Scott's *Emergent Energy* (Figure 2) is an iterative, reflexive bi-modal (audio-visual) system of interaction in which motion, speed, number of users and position in a space (triggering pressure sensitive floor mats) determine the growth of a visual design drawn with a Lindenmayer (L-system) generative algorithm [3; 4; 14; 25; 26; 28]. The design artefact is an embedded history of the movements, interactions and number of people who produced it (Figure 3 & Table 2). Sound is a spatial experience, inseparable from context [21] so it is logical to utilise 3D spatial interaction to measure activity and manipulate sound.

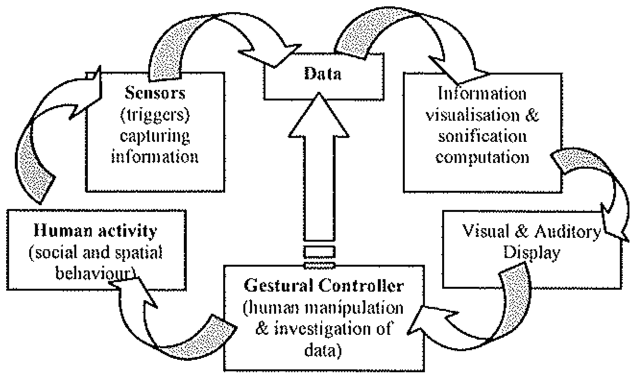


Figure 1. Knowledge flows from socio-spatial activities to sensors that capture data, through a computational sonification process to real time display. This loop is completed when gestural controllers are used for spatial interaction to manipulate or investigate this data.

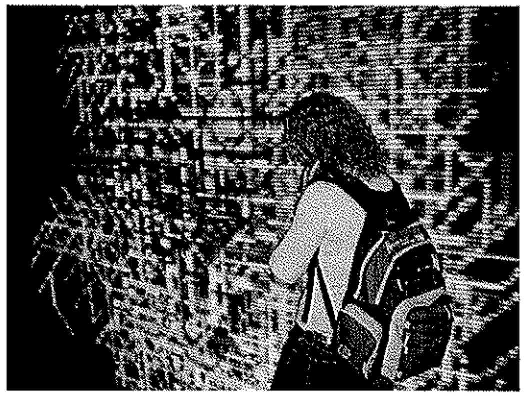


Figure 2. Beilharz, Vande Moere & Scott's L-system generator patch in Max/MSP & Jitter software [11] used to create branched visualisations on screen. In the corresponding sonification, the number of people relates to dynamic intensity, position to *timbre* (tone colour) and speed to frequency (pitch) [3].

2.2 Gesture Controllers

As computing moves towards people acting in spaces, deviating from our currently sedentary desk-bound lifestyle, the importance of the spatial interaction and experience design, the way in which information is represented, becomes essential. Building architecture and informative display become one (Figure 5).

Enabling buildings with responsive, "understanding" and feedback capabilities facilitates flexibility and accessibility to assist environmental comfort, navigation for the visually impaired, building awareness, gerontechnology (technologies assisting the elderly), and automated and augmented tasks for the physically disabled. Nanotechnologies - embedding minute sensor technologies in furnishings, surfaces and pre-fabricated building materials - facilitate localised sensate regions and unobtrusive (wireless) distributed networks for data collection. Gesture controllers provide an instinctive, intuitive way of communicating with information.

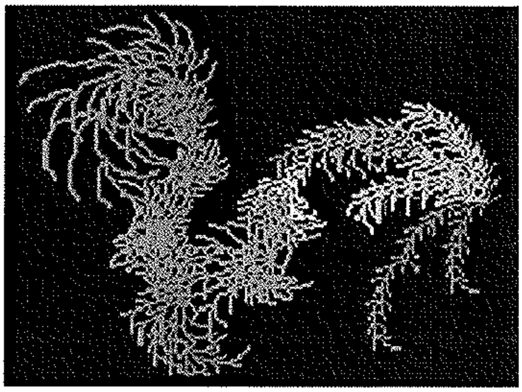
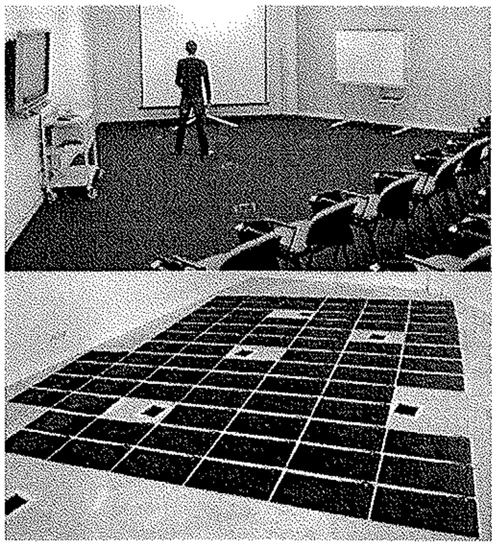


Figure 3. The Lindenmayer algorithm produces different colours (RGB values) determined by the position of users on pressure sensitive mats and levels of activity affect the branching characteristics. Colour corresponds to different *timbre* (tone colours) in the sonification and *y*-axis position determines the pitch (frequency) produced [2].



Figures 4 & 5. The Sensate Lab (2 views) showing the "invisible" pressure sensitive floor mats embedded underneath the carpet, triggering the visual and auditory sound system and (bottom) before carpeting the grid of pressure mats laid on the floor, networked to the Teleo (analog to digital in/out) modules for conversion to a USB interface [17].

Table 2. Sonification schema of mapping correspondences [1].

Sonification	**Visualisation**	**Activity / Trigger**
Pitch (frequency)	Length/scale/scope of graphic display on screen	Distance between activities / motion
Texture/density	Density of events / number of branches or iterations of generative algorithm (embeds history by amount of activity)	Volume of activity, number of users and social threshold
Rhythm/tempo of events	Proximity and rapidity of display (animation)	Speed of actions, punctuation of triggering events, tied to velocity of events
Intensity/dynamic loudness	Heaviness and distinction of on-screen drawing	Intensity/magnitude of triggering events
Timbre (tone colour)	Colour and distribution on visual display (screen)	Region/spatialisation – topology, zoning
Harmony	Design artefact	Multi-user manipulation

Figures 6 and 7 show different controllers for manipulating information in 3D space - Reed Kram's *Three Dimensions to Three Dimensions* uses haptic (tactile) cubes as creative tools for expression while sensors attached to digits and limbs can be used as the gestural (non-tactile) controllers for music [6; 21; 23] and the high precision gesture glove [5] provide similar sensitivity and responsiveness to the captors (gesture controllers) to be used in this project for data control.

The science fiction film, Steven Spielberg's *Minority Report* [16] forecasted a kind of interface that is already now achievable: spatial and gestural manipulation of video and computer data on a transparent screen suspended in 3D space (Figure 8). The notion behind gestural information access is an important one: dissolving the hardware and unsightliness of computer interfaces.

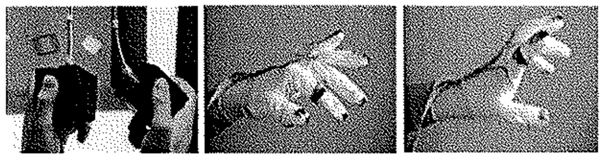


Figure 6. Haptic (tactile) manipulable cubes in Reed Kram's *Three Dimensions to Three Dimensions* (left) are creative tools for expression while sensors attached to digits and limbs can be used as gestural controllers for music (right) [6; 21; 23].

3. SIGNIFICANCE AND INNOVATION

Completing the feedback loop in data sonification enabling interaction with source information provides a technical solution to passive sonification and a new approach to the field of data sonification.

So far, in the field of 3D information representation, most emphasis is given to information visualisation. There is a gap in our knowledge for the other senses in 3D space. This project addresses this both through 3D auditory representation and 3D spatial interaction by utilising haptic sensations [23], tactile sensation, wireless gesture and kinaesthetic perception to affect the data source.

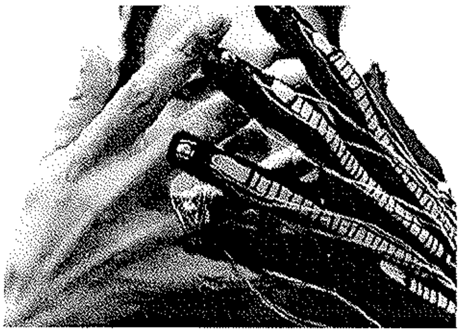


Figure 7. A gestural Cyberglove controller that produces a high degree of accuracy transmitting spatial, position, rotational, gyroscopic, velocity and flex data. The precision facilitates interaction with information representation in 3D space [5].

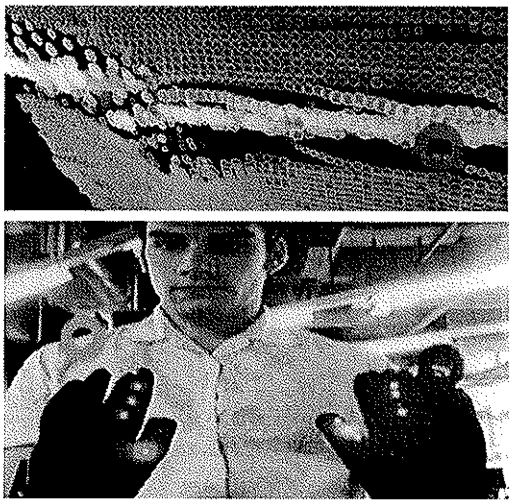


Figure 8. Justin Manor's *Manipulable Cinematic Landscapes* [16] is a glove-controlled cinematic landscape interface in 3D space.

3.1 A New Way to Interact with Aesthetic Computing

Current sonification is limited by its passive, non-interactive, one-way flow of information from source to display without further mechanism for human interaction and manipulation. This project addresses this gap by providing a link between spatial axes and spatialised 3D display of audio using gesture controllers. The advantage of using spatial interaction is to maintain the trend away from keyboard/mouse (static, restrictive) input devices and to localise the interaction in a socio-spatial context. No current work links gesture controllers as used to control music, performance and real time composition with real time sonification. This opportunity provides a new way to interact with aesthetic computing.

3.2 Integrated Informative and Aesthetic Computing

The focus of many sonifications and ambient displays is purely informative without attention to the value of aesthetic display in the workplace, social spaces and augmented realities. Auditory cues, alarms, abstract electronic sound not based in a musical framework, are difficult to listen to for sustained periods of time and certainly offer no cultural benefit as public sound installation. The objective of this display integrates informative and aesthetic computation. John Maeda (founder of the MIT Aesthetics and Computation Group), advocates that bridging the chasm between art and science and delivering digitally sophisticated design merges artistic expression with digital technology, leading to "a greater understanding and richness of human experience" [16]. This framework brings together aesthetic computing and musical composition in the mapping process.

3.3 Spatial Participation by the User

An important contribution of this system is cultural awareness that is developed through participation in socially reflective contemporary auditory display. The proposed model constitutes a socio-spatially controlled digital instrument. It provides an innovative approach to user participation (interaction) using newly available sensing and controller technologies to involve users in the creation and understanding of auditory space. Detailed explanations of physical interfaces in the electronic arts [5] demonstrate the wide array of gestural interaction modes (ranging from affordable to experimental, generalised to precision instruments) that have yet to be utilised for communicating with information sonification in real time.

3.4 3D Interactive Information Sonification

Gestural and augmented reality interaction occur through motion in three-dimensional space. The emerging paradigm of 3D spatialised sound, enabled by sound design softwares, such as IRCAM SPAT or the work of John Chowning [21], has new implications for gestural interaction with sound. It is logical to conflate 3D spatialised representation with 3D spatial interaction. This framework integrates display and interaction in three dimensions, or four if the time axis is included. Spatialised audio is commonly used in entertainment and sound design. VBAP (Vector Base Amplitude Panning) allows conventional panning for location of sounds. The SPAT environment allows algorithmic control of a richer group of parameters, creating greater perceptual realism, i.e. effective **virtuality**: spatialisation and panning, reverb, room liveness/heaviness, ambience, Doppler effect with moving sounds (pitch transposition), distance placement, air absorption, input EQ. These controls contribute not only to the accuracy of perception but also to the reality and sustainability (listenability) of sounds in public space. Gestural interaction has occurred with 3D visualisation [22] and 3D sound design [24] but this project proposes a new approach by integrating 3D gestural control in spatialised sonification of information.

4. APPROACH

Translating gestural interaction in 3D space into **affectors** (software commands) that manipulate the source data demonstrates a complete cycle in which social activities and movement throughout a room produces the sonification that, in turn, is transformed by the participant. Affectors, in programming terms, are gestures that trigger a change in information, e.g. motion acceleration thresholds, direction, velocity. The specific affectors are determined by calibration of the data captured (i.e. the type of sensors/controllers used).

The relations between gestures and affects (transformations) are determined in the mapping process. Spatialised audio display, e.g.

IRCAM's multi-dimensional real time SPAT software [12], is used to locate and contour sound attributes in 3D space, making it easier to identify, distinguish, then manipulate specific sounds. Moving the sound or interacting with it gesturally is essentially a **reverse-mapping** procedure that alters the data set. Successful gestural interaction with data sonification is demonstrated by using gesture controllers to change the data set producing the sonification experienced by the participants.

4.1 Method

Figure 9 shows the different parts of the interactive sonification model. Table 3 explains the technical implementation of these parts.

The **sensing** process uses the Sentient Lab (enabled by pressure mats, proximity, video and other sensors) (Figures 4 and 5) to gather socio-spatial information about motion, activity, flow and environmental conditions. In the **sonification** process socio-spatial measurements are mapped to auditory representation that is both informative and musical. Correlations are designed to make the representation readily and intuitively understood. Attributing behaviours to characteristics of sound – pitch, velocity, textural density and tone colour occur in this phase. The **spatialisation** process distributes the output to a 3D spatialised audio mapping in which physical sound placement corresponds to gestural directions, plane, rotation and acceleration. **Interaction** enables the participant to transform the data representation using gesture controllers. Gesture recognition is tied to spatialisation and affecting is tied to information mapping. This project implements wireless UDP gesture controllers that permit mobility and freedom of motion [15]. The Kroonde is a wireless sensor interface dedicated to real time applications. Sensors are connected to the wireless transmitter box worn by the user. The wireless base transmits through a high bandwidth Ethernet connection to the host computer. The Kroonde can also send the data via MIDI. The range of sensors available includes acceleration, gyroscope, motion, pressure, temperature and photosensitivity.

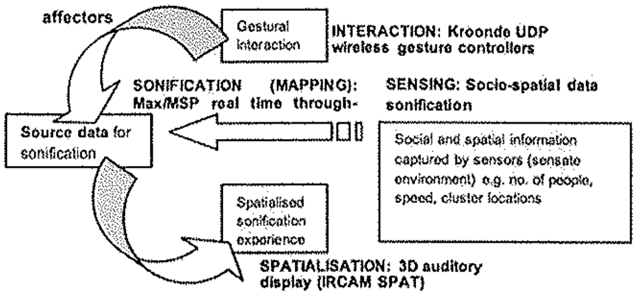


Figure 9. Gestural interaction using gesture controller devices can be used to affect (change) the source data that produces the information sonification in real time. The source information is derived from socio-spatial data about human behaviour in a sensate architectural space.

Table 3. Software and hardware used to implement the different stages of the real time spatialised interactive auditory display.

Process	Approach	Hardware	Software
SENSING	Capture information: number and location of people, timing, proximity to specific objects, environmental conditions	Pressure mats, proximity IR, photosensitive, temperature sensors, video cameras - connected by Teleo modules (MakingThings, 2003)	Max/MSP + Jitter (IRCAM, 2003)
SONIFICATION	Map activity values to sound attributes using associations that are easily understood (Beilharz, 2004a) designed to produce an aesthetic artefact		Max/MSP + Jitter
SPATIALISATION	Distribute output to spatialised multi-channel audio display		SPAT (IRCAM, 2004)
INTERACTION	The LaKitchen captors (gesture controllers) convey spatial information about velocity, acceleration, direction and proximity of user interactive gestures with high sensitivity and precision	Kroonde wireless UDP transmitter and receiver (Henry, 2004; IRCAM, 2003; LaKitchen, 2004) with gyroscope, acceleration, 2D and 3D motion gesture controllers	Max/MSP + Jitter and Open Sound Control object (CNMAT, 2004)

Criteria for clear differentiation in auditory display, based on a review of auditory perception and cognition [27] are used to ensure easily recognised representation [29; 30] and aforementioned sonification mapping principles (similar to Table 2) are developed in detail in this project.

5. RELATED PROJECTS DEMONSTRATING GESTURE-CONTROLLED INTERACTION WITH SOUND

The 'Sensor Cow' project, using wireless gesture controllers fixed to a calf, is used to exemplify real time computation and representation issues to convey spatial motion in an easily recognised sonification that is suitable for ambient display or intuitive interaction. The 'The Music Without' performance and the *Sydney Esquisse* exhibition 'Sonic Kung Fu' examples following show two ways in which people use gesture controllers to augment and shape their environment by interacting with sound.

5.1 'Sensor Cow' (Wireless UDP Gesture Captors)

In the Sensor-Cow project (Figure 10), the La Kitchen Kroonde Gamma receiver, transmitter and sensor equipment were used (Figure 11). The sensors used were acceleration, gyroscopic and bi-directional motion captors. UDP is a protocol for high speed, high precision data-acquisition.

Figure 10 shows the way in which these sensors and transmitter are attached to the calf for capturing the data that generates the sonification. The outcome was a sonification of the calf's motion.

The highly sensitive mercury motion sensors operate between extremes of direction, registering a "bang" (signal to the sonification program) when changes in direction occur. Thus these were attached to the front legs to indicate steps as the calf walked. When calibrated, the gyroscopic and accelerator sensors produce a broad spectrum of values spanning a gamut of 1024 increments mapped to audible pitches. The acceleration sensor values were scaled to 128 distinct output values. These sensors were attached to the calf's ear and forehead, respectively, because these regions isolate significant independent gestures. The calf naturally raises and lowers its head to eat, when flicking away flies, in response to people and other animals - it is expressive and the range of motion is diverse. While naturally following whole head movements, the ear is also flicked and rotated independently producing an audibly recognisable gesture.

A distinctive *timbre* (tone colour) was attributed to each sensor in order to make it possible to distinguish the sounds arising from each sensor. The rhythm, pace/acceleration and velocity of action are heard in real time. Hence the correspondence between rapid gestures and rapid sonification is literal. For both the acceleration and gyroscopic sensor, extremes of motion away from the median, drives the pitch in directional extremes away from a central pitch region. The direction of pitch, ascending and descending away from the mean, corresponds to the x-axis direction of motion so that changes in direction are audible and circular motions of the ear and head produce sweeping auditory gestures that reinforce the audio-visual connection between activity and sonification. The sonification was programmed in Max/MSP (+Jitter) using La Kitchen's Kroonde Gamma recognition [9]. The computer receives data via Ethernet connection at a fixed IP address. The hardware is recognised using CNMAT Berkeley's Open Sound Control [8] object.

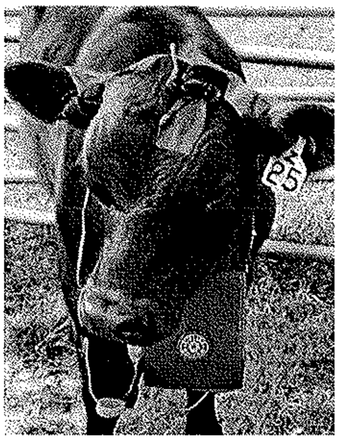


Figure 10. Bi-directional (mercury) motion sensors are attached to the calf's front legs, a gyroscopic sensor on the forehead and accelerometer on his right ear. The pouch hanging around his neck contains the radio frequency transmitter that sends the real time data to the (La Kitchen) Kroonde Gamma wireless UDP receiver [15]. It is connected by Ethernet to the computer running the data sonification with Max/MSP object-oriented programming environment.

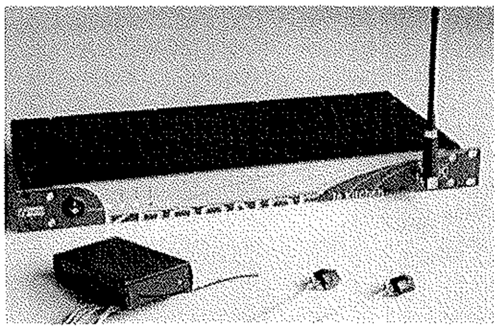


Figure 11. Kroonde Gamma wireless receiver box, transmitter and attached sensors. The sensors, cabled to the transmitter box, are worn by the user who is then free to move.

5.2 'The Music Without': Making Music from Motion

'The Music Without' is concerned with exposing the motion of music. Real time computer music responds to sensors placed on the violinist's left-hand finger and forearm and the bowing arm. The gyroscopic, binary-motion and acceleration sensors convey the intensity, physicality and movement (outside forces) that performing involves (Figure 12). Typically, we think of the music within, of the source of musical creation being the mind (composer) and the heart (interpretation). Most reactive, responsive computational real time music systems analyse and respond to pitch, harmony and rhythm. Thus, most systems for improvisation and collaboration are responding to the musician's inner music by "listening" to the auditory outcome.

In contrast, this system creates a response to the forces producing sound, hence 'the music without'. The 'other musician' here is a sonification of the external energies creating music. The system is generating a musical response to physical gestures perceived by the sensor devices. It is not so much listening as feeling, or experiencing, the process of performing. This work emphasises a different and often overlooked part of the music-creating process.

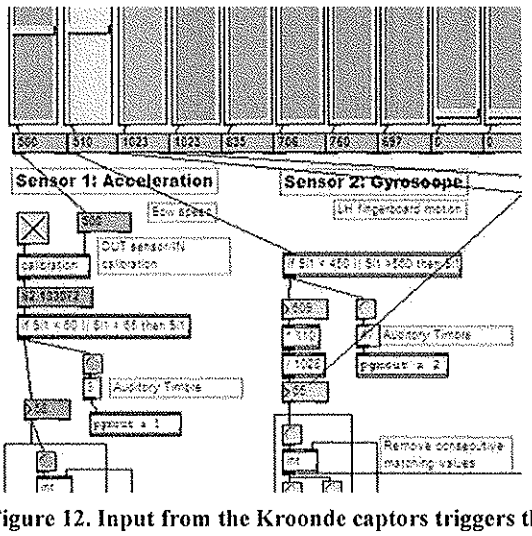


Figure 12. Input from the Kroonde captors triggers the auditory representation of motion in the Max/MSP patch. The resulting sound is a sonification of the physical exertion and motion required to produce the solo violin improvisation.

The resulting music is energised by movement with audible flourishes associated with large gestures of the performer. Rapid and vigorous activity produces loud and dense bursts of computer music, while specific sensors respond to particular aspects of gestural interaction. A mercury binary sensor is attached on the left-hand middle finger, sending a high-pitched pulse on each change of direction, to convey the rhythmical and persistent infusion of vibrato. Another binary sensor is attached to the bowing arm, close to the fulcrum to capture the beats produced by changing bow direction, again reinforcing the excitement or calmness of the music (Figure 13). The extremely sensitive gyroscopic sensor is attached to the left forearm to capture the significant movements of the position shifts. The acceleration sensor is attached to the bowing arm to convey the almost constant acceleration and deceleration trends and rotations of the right hand. Each sensor's signal is differentiated by *timbre* and register and each has a threshold of inactivity that must be overcome to produce sound.

While this is a composition for listening to, the visual element relating intensity to its auditory result is an important part of the experience. Video of the player producing the sonification subtly reinforces the notion of music from without. The electric violin performance is live improvisation. La Kitchen 'Kroonde Gamma' captors (sensors) and wireless receiver transmit the motion data to the sonification patch programmed in Cycling 74 Max/MSP.

Figure 13. Sensors are attached to the violinist's left and right hands and arms to capture the physicality of performing: pictures the acceleration sensor and motion direction sensing representing bowing activity.

5.3 'Sonic Kung Fu': Colour-Sensing Gestural Interaction with Sound

'Sonic Kung Fu' by Jakovich and Beilharz (at *Sydney Esquisse* exhibition, March 2005) is a sonic art installation in which participants wear coloured gloves to perform gestures that produce a real time responsive audio sound-scape (Figure 14). A web cam receives the visual gesture information. The Max/MSP patch responds to the motion of the centre-point of a specific colour (calibrated to match the glove being worn), responding with auditory variation across a range of x and y- axis values (Figure 15). The immediacy and mapping of this work was intentionally as simple and intuitive as possible for recognition to invoke interaction by passers-by in a gallery setting. The result was that users spent considerable time with the "instrument" learning to understand and control its performance.

6. CONCLUSION

Three projects using gestural and motion triggers to affect sound demonstrate the potential of gesture controllers in interactive auditory display. This paper sets out a framework for linking the use of gesture-controlled audio with traditionally passive information sonification. The bridge provided by affecting change in a data set achieved through gestural manipulation of sound completes a loop in the cycle of human-computer interaction. Importantly, the proposed method of transforming data also provides a 3D spatial mode of interaction that is more suited to 3D interaction environments, such as VR and AR. The use of auditory display increases immersion, broadens attentiveness and especially suits information assimilation in already visually-rich environments or those situations where auditory acuity is superior (time-based patterns or low-visibility conditions).

7. ACKNOWLEDGMENTS

Thanks to Joanne Jakovich, collaborator in the 'Sonic Kung Fu' project and research assistant developing the auditory interaction in 'Emergent Energies'. Thanks to Emmanuel Jourdan at IRCAM, Paris, for technical expertise with SPAT.

Figure 14. Gestural interaction with auditory display created in response to colour tracking of the spatial glove motion.

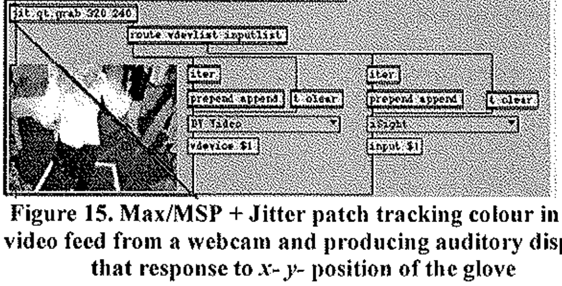


Figure 15. Max/MSP + Jitter patch tracking colour in the video feed from a webcam and producing auditory display that response to *x*- *y*- position of the glove

8. REFERENCES

[1] Beilharz, K. (2004a). "(Criteria & Aesthetics for) Mapping Social Behaviour to Real Time Generative Structures for Ambient Auditory Display (Interactive Sonification)", *in* E. Edmonds and R. Gibson (eds), *INTERACTION - Systems, Practice and Theory: A Creativity & Cognition Symposium*, Creativity and Cognition Press, The Dynamic Design Research Group, UTS, Sydney, pp. 75-102.

[2] Beilharz, K. (2004b). "Interactively Determined Generative Sound Design for Sensate Environments", *in Sound and Music Computing*, IRCAM, Paris.

[3] Beilharz, K. (2005). "Responsive Sensate Environments: Past and Future Directions: Designing Space as an Interface with Socio-Spatial Information", *in* B. Martens and A. Brown (eds), *CAAD Futures*, Wolters Kluwer Academic Publishers, Netherlands, Vienna, pp. in press (13/01/05).

[4] Bentley, P. (1999). *Evolutionary design by computers*, Morgan Kaufmann Publishers, San Francisco, CA, USA.

[5] Bongers, B. (2000). "Physical Interfaces in the Electronic Arts. Interaction Theory and Interfacing Techniques for Real-timePerformance", *in* W. W. Wanderley and M. Battier (eds), *Trends in Gestural Control of Music*, IRCAM - Centre Pompidou, Paris.

[6] Choi, I. (2000). "Gestural Primitives and the Context for Computational Processing in an Interactive Performance System", *in* W. W. Wanderley and M. Battier (eds), *Trends in Gestural Control of Music*, IRCAM (Institute of Research in Computer and Acoustic Music) Centre Pompidou, Paris.

[7] Ciardi, F. C. (2004). "sMAX: A Multimodal Toolkit for Stock Market Data Sonification", *in* S. Barrass and P. Vickers (eds), *Proceedings of ICAD 04 -Tenth Meeting of the International Conference on Auditory Display*, Sydney, Australia.

[8] CNMAT 2004 Open Sound Control (OSC) http://cnmat.cnmat.berkeley.edu/OSC/Max/#downloads

[9] Henry, C. (2004). *La Kitchen Kroonde Gamma - User Manual & Max Patches*, La Kitchen, Paris.

[10] Hermann, T., Baier, G. and Müller, M. (2004). "Polyrhythm in the Human Brain", *in International Conference of Auditory Display (ICAD)*, Sydney, Australia.

[11] IRCAM (2003).Max/MSP, Cycling 74: Max/MSP is a graphical object-oriented programming environment for real time control of music, audio, and multimedia objects, capable of hardware and software integration, USA. http://www.cycling74.com/products/maxmsp.html

[12] IRCAM (2004).SPAT: Real time audio spatialisation program, http://forumnet.ircam.fr/rubrique.php3?id_rubrique=104

[13] Janata, P. and Childs, E. (2004). "Marketbuzz: Sonification of Real-Time Financial Data", *in International Conference of Auditory Display (ICAD)*, Sydney, Australia.

[14] Kreveld, M. V., Overmars, M., Schwarzkopf, O., Berg, M. d. and Schwartskopf, O. (1997). *Computational Geometry: Algorithms and Applications*, Springer Verlag

[15] LaKitchen 2004 Kroonde Gamma 16-sensor Wireless UDP Interface http://www.cycling74.com/products/kroonde.html 03/08/04.

[16] Maeda, J. (2004). *Creative Code*, Thames and Hudson, London.

[17] MakingThings 2003 Teleo Modules and Sensor Devices http://www.makingthings.com/products/products.htm 1/1/04.

[18] Nesbitt, K. V. and Barrass, S. (2002). "Evaluation of a Multimodal Sonification and Visualisation of Depth of Market Stock Data", *in* R. Nakatsu and H. Kawahara (eds), *International Conference on Auditory Display (ICAD)*, Kyoto, Japan.

[19] Paine, G. (2004). "Reeds: A Responsive Sound installation", *in International Conference of Auditory Display (ICAD)*, Sydney, Australia.

[20] Polli, A. (2004). "Atmospherics / Weather Works: A Multi-channel Storm Sonification Project", *in International Conference of Auditory Display (ICAD)*, Sydney, Australia.

[21] Pottier, L. and Stalla, O. (2000). "Interpretation and Space", *in* W. W. Wanderley and M. Battier (eds), *Trends in Gestural Control of Music*, IRCAM (Institute of Research in Computer and Acoustic Music) - Centre Pompidou, Paris.

[22] Roeber, N. and Masuch, M. (2004). "Interacting with Sound: an Interaction Paradigm for Virtual Auditory Worlds", *in International Conference on Auditory Display (ICAD)*, Sydney.

[23] Rovan, J. and Hayward, V. (2000). "Typology of Tactile Sounds and their Synthesis in Gesture-Driven Computer Music Performance", *in* W. W. Wanderley and M. Battier (eds), *Trends in Gestural Control of Music*, IRCAM (Institute of Research in Computer and Acoustic Music) - Centre Pompidou, Paris.

[24] Sheridan, J., Sood, G., Jacob, T., Gardner, H. and Barrass, S. (2004). "SoundStudio4D - a VR Interface for Gestural Composition of Spatial Soundscapes", *in International Conference on Auditory Display*, Sydney.

[25] Skiena, S. S. (1997). *The Algorithm Design Manual*, Telos/Springer-Verlag (Book and CD-ROM edition)

[26] Skiena, S. S. (2003) Analysis of Algorithms for Music http://www.cs.sunysb.edu/~algorith/lectures-good/index.html 21/11/03.

[27] Song, H. J. and Beilharz, K. (2005). "Time-based Sonification for Information Representation", *in World Multi-Conference on Systemics, Cybernetics and Informatics*, Orlando, USA, pp. in press 28/01/05.

[28] Vande Moere, A. and Beilharz, K. (2004). "Interaction Design for Smart Spaces – a Constructivist Design Studio", *in Proceedings of the 38th Australian & New Zealand Architectural Science Association (ANZAScA) Conference*, University of Tasmania, Hobart, pp. 335-342.

[29] Vickers, P. and Alty, J. L. (1998). "Towards some Organising Principles for Musical Program Auralisations", *in* A. Edwards and S. A. Brewster (eds), *International Conference on Auditory Display (ICAD)*, Glasgow, Scotland, U.K.

[30] Walker, B. N. and Kramer, G. (1996). "Mappings and Metaphors in Auditory Displays: An Experimental Assessment", *in International Conference on Auditory Display (ICAD)*, Palo Alto, California, USA.