SONIFYING EVERY DAY: ACTIVATING EVERYDAY INTERACTIONS FOR AMBIENT SONIFICATION SYSTEMS

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ABSTRACT

Ambient information systems have been investigated widely in the visual modality, but ambient sonification systems are rare and investigation is limited by comparison with ambient visualisations. However, the auditory modality is well-suited to the task of interpreting quantitative information communicated through sonification, while not requiring interruption to the user's current actions, as opposed to a visual system that requires visual attention. This paper investigates an approach to ambient sonification that activates everyday interactions, by using sensors to pick up interactions that users make with physical objects in a domestic environment. These actions are then used to trigger or control ambient sonifications. These sonifications are based on the information obtained from the same sensors or from information sourced from data services. The design patterns and implementation concerns are discussed and several prototype sonifications presented.

1. INTRODUCTION

Sonification has been investigated for some time with a view to developing a replacement representation method for visualisation, either in hands free situations or for the visually impaired. While much has been accomplished, and the strength of sonifications have been demonstrated numerous times, situations where sonification is useful have generally been limited to data analysis contexts. Ambient *sonification* systems, in workplace or domestic contexts, have had limited investigation, but may be an alternative area where sonification can find significant acceptance.

One seemingly inherent drawback of ambient visualisation systems are their requirement for attention to be devoted to a display, or to project an image or lighting consistently. Any introduction of visual representations of data requires a user to change their behaviour to incorporate a period of attention to this object into their program of actions – for instance, by checking their phone to get data on the day's weather.

This research seeks to develop a system that exploits a flexible set of everyday actions to create an 'invisible' interface to ambient data representations through sonification. We explore a set of designs that exploits a sonification's ability to seamlessly inject itself into a pattern of domestic behaviour without significant disruption and without requiring direct attention.

1.1. Ambient Information Displays

Sonification research takes a quite specific set of assumptions of the sonification user. It often assumes they are technically gifted and knowledgable about the data they are interacting with, and that they can both manipulate data to create numeric analyses, and manipulate audio systems to create new sounds.

Everyday design and everyday situations have been studied before (eg. Norman [1]), although research interest can often be quite sporadic and idiosyncratic. Everyday use of designed artefacts is characterised by a needs-based flexibility and customisation that often conflicts with the designer's original intention or expected context. For instance, a clothesline may be used for drying photos, or a storage box may be used for growing plants. This customisation process is even more important for computing systems as they often provide a set of options as their basis.

Ishii and Ullmer [2] provided an early vision of ambient human-computer interfaces, demonstrating the *ambientROOM* prototype system. Wisnecki et al. [3] showed the difference between the desktop's 'small window' onto the digital world, and the idea of embedding digital information into 'tangible bits', graspable computing interfaces that move away from the screen-based desktop metaphor and into everyday life. Gaver's research into the effect of information display in a domestic context is very influential – in the idiosyncratic prototype 'The Drift Table' he shows the 'playful exploration' that can be achieved using a 'ludic' interface to computing systems [4].

A highly cited taxonomy of Ambient Information Systems [5], defines four characteristics of their design: information capacity, notification level, representation fidelity, and aesthetic emphasis. 'Information capacity' is the amount of information that can be presented (either in space or time). 'Notification level' describes how much the information presented by the system is designed to interrupt the user. 'Representational fidelity' describes the way in which the information is represented by the system, and Pousman and Stanko propose five groups of representation - indexical (maps, photos), iconic (cartoons, drawings), iconic (metaphors), symbolic (language symbols), symbolic (abstract symbols). Finally, 'aesthetic emphasis' describes the importance of aesthetics within the display.

A similar, more recent, taxonomy, with a wider range of design dimensions, was proposed by Tomitsch et al. - it focuses on transition, notification level, temporal gradient, abstraction level, representation, modality, source, location, dynamic of input [6]. They argued that their taxonomies' extra dimensions increase its descriptive power. Notably, their categorisation of 19 separate ambient information systems into the five different modalities highlighted only one system that used the auditory modality, and even then not exclusively.

A simple example of the type of representation designs that ambient systems have facilitated is the 'power-aware energy cord' [7], a power cord that glows when power is travelling through the cord. Streitz et al. [8] envisage systems that work in different spatial zones, from the ambient to a notification zone to interactive zone. Vogel and Balakrishnan [9] extend the idea of ambient displays to the public space. Finally, Zigelbaum et al. [10] show methods for developing control of systems without directly touching the system, which is important for systems that exist outside of this screen-directed-gaze context that exists within desktop or mobile computing.

1.2. Hands Free Sonification

Hands free situations are an important sonification context - allowing a user to work without paying attention to an information stream presented using a visual display means that a user can simultaneously monitor an information source while attending to another task. Information stream monitoring can be quite uninteresting in most situations, except when emergencies arise, by which stage the user's attention may have drifted from the monitoring task. The use of sonification for the information representation translates the monitoring task to the auditory modality, meaning that with an appropriate design, the sonification system can attract the user's attention to the information stream that is showing an abnormality of some description.

One of the earliest examples of the use of handsfree sonification is the Geiger Counter, and it is one of the most ubiquitous sonifications in use today. Its design allows a user to pass through an area while being presented with a constant stream of information about radiation – when the information requires attention the sonification rapidly becomes both louder and more 'frantic', due to the the interval between sounds shortening. The Geiger counter has the added advantage of being a direct translation of data - with a simple translation from detection to sound on an electrical, rather than digital, basis.

An early example of research into the use of sonification for the purpose of monitoring was pioneered in Cohen's work [11]. Hermann et al. [12, 13] designed systems for monitoring sounds using various methods, one of which relied on vocal transformations to deal with the complexity of multi-dimensional time series data. Fitch and Kramer's highly cited paper on sonification [14] described the superiority of sonification for a highly time-dependent monitoring task – anaesthesia.

Brazil and Fernström investigated the use of sonification as an ambient display context. They used a questionnaire to discuss the user experience of an ambient sonification system situated in their research laboratory [15]. Mauney and Walker created of sonifications for monitoring stock data that used environmental sounds such as insects and thunder [16].

However, much sonification research has a set of hidden assumptions. They presuppose: that the user will be technically proficient in both data analysis and sound design; that the user will for some reason choose to use sonification *instead* of visualisation (although this can be quite important for the blind and visually impaired); and that therefore a system should attempt to provide a visualisation in an analogous but alternative, rather than complementary, way to a visual graphing and statistics system.

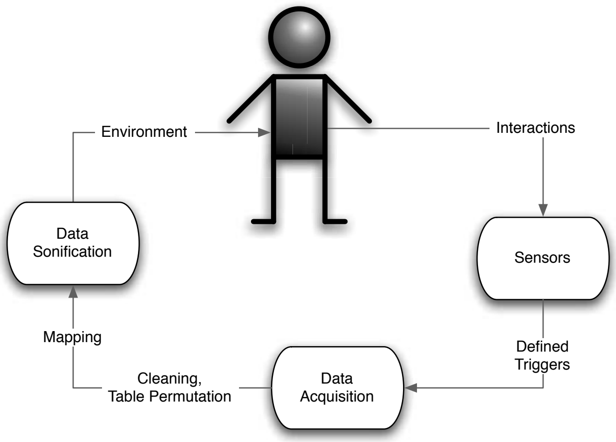

Figure 1: The interaction framework described in this research is similar to many interaction frameworks, but there are a couple of important factors to consider for this particular context.

2. FRAMEWORK

In this section we develop a simple framework for the description of simple everyday interactions, which uses five stages: 1.

- The first stage is the interactions themselves, and the associated meanings.
- The second stage is the sensor used to capture the interaction, which reduces the interaction to a digitised signal of some type, the nature of which determines the following stage.
- The third stage concerns the data acquisition phase, which can be carried out using network data sources, or through storage of interaction data, which can be used.
- The fourth stage requires the data to be sonified using typical sonification methods.
- The fifth stage is the user listening and responding (or not) to the data sonification, including perhaps repeating or changing their interaction in some manner.

2.1. Interactions

Interactions have typically been studied within the Human-Computer Interaction discipline, and have been mainly understood to be the purposeful interaction with a system, with the expectation of some kind of specific response. The focus is on the communication of the computer's or software's capabilities and the interpretation of the user's needs. In the context of everyday interaction, however, the user is often not directly attending to the computing system. Rather they are focused on the everyday task they are performing, and the ambient display intrudes into the environment to hopefully anticipate a need of the user. Also, their response cannot often be assessed directly - an effective ambient information system will not require the user to respond to it directly, and therefore it cannot rely on the user interface possibilities available to assist the user in customising the system to their particular needs.

2.2. Sensors

Many sensors may be used to exploit simple interactions, and a list of these will help to describe the range of interactions that can be captured. These include:

Noise Sensors: are small electret microphones attached to a small amplifier and which output a DC voltage rather than an AC signal. These can be used to easily measure change in the acoustic conditions, especially change resulting from sources such as speech. With the electret microphone replaced by a contact microphone they can also be employed as a knock sensor.

InfraRed beam sensors: can be used as a short-range threshold sensor - due to the narrow beam of light that an IR LED projects, an occlusion of that relatively controlled light path can trigger the sensor.

Distance Sensors: Ultrasonic or infrared distance sensors can be used to measure the distance from a source position to a wall or door. This may be used for various situations where a distance is known under normal circumstances (eg. drawer closed, door shut), but will change when interaction occurs.

Hall Sensors: can be used to capture the interaction of a magnetic field in a space. Generally they are used with a magnet that moves between a position close or far away from the sensor.

Current sensor: One other sensor that is useful is a current sensor - measuring the current flowing through a power cord by means of induction. Such a sensor can detect whether a device has been turned on and is using current.

Compass: A useful sensor is a compass - as it provides a method of creating a controller out of any device that can provide information about angle in a precise manner. For instance, a compass attached to a swinging door will travel through up to 180 degrees of rotation. This rotation can be used as an interface control method.

It is also useful to describe the difference between the two main classes of sensor interface - accelerometers, compasses, and gyroscopes are more complex sensors that require a *digital* interface to interface with the computing platform - an interface that is often more complex to configure for different contexts, and is specific to the sensor concerned. Many other sensors provide only an analogue voltage as an interface, and are therefore very simple to configure, and can be swapped to other sensors relatively rapidly without significant reconfiguration being required.

2.3. Data Acquisition

The system can employ two alternative sources for data acquisition - data that is created by recording the sensor outputs (for instance the times a door is opened at), and data that is acquired from an external source (such as a web-based weather data service).

The storage of interaction or usage data created by the sensors can provide a description of a pattern of behaviour that may be important to recall for the user. This is a way of providing a reflection of the user's behaviour, for the purpose of monitoring or change. For instance, data about opening a fridge door may be used to give information to the user about their snacking behaviour, and information about the user's use of energy from a particular appliance may be used to regulate their use of that appliance.

Alternatively, data may be generated by reading external sources of real-time or regularly updated data. This is a traditional method for obtaining data for ambient information display, and allows the user to be presented with information that may be difficult or inconvenient to obtain in a daily routine. The rise of mobile and ubiquitous computing has so far been mainly designed to give users the option to seek out data and information - often from traditional sources such as newspapers - but ambient information display has reversed that relationship, meaning that users can set the data to seek once, and then the display platform will present the data as part of the living environment.

2.4. Data Sonification

Data sonification is quite well-understood by this research community, so I will focus primarily on the specifics of the presentation situation and the way in which that affects the design of the sonification. Generally, the needs and design criteria for ambient information sonification are not well understood.

Firstly, the ambient display context is specifically focused on the presentation of time-series information that has a relationship with the current instant. It seems unlikely (although not impossible) that a data display would be independent of the current time in an ambient context. Therefore, in most contexts the sonification design requires a time-axis context to be established that is referenced against the current time.

Secondly, the ambient display context does not allow for explanation and inspection of the sonification design - a system that incorporated a sophisticated user interface would be intrusive and unnecessarily complex or expensive for this context. User interaction must be limited and cannot be used to provide full graphical inspection and exploration ability. There is limited research available into the presentation of scales and other context for sonifications [17] in data analysis contexts, and the ambient context for sonification requires further careful consideration.

Thirdly, an ambient sonification context needs to deal with problems of annoyance, intrusiveness, repetition and bleed. The auditory modality is excellent for providing information that is accessible to people who may be paying attention to other tasks. However, there is the possibility that they may be paying attention to those other tasks and not wish to be disturbed. The duration and design of the sonifications used are crucial parameters, and much research has provided guidance on design for high-workload contexts. The use of an ambient display contexts, however, needs to carefully assess this research and interpret it for a different context.

Finally, data sonification in an ambient context needs to be designed to be both attractive and inviting - something that sonifications sometimes sacrifice in order to attain accuracy.

Effective interaction systems do not assume that the user's response to the system output will be passive, fixed or predictable. Especially for sonification, providing methods for replay, interaction and control of the sonification created, however coarse and straightforward, does help to provide an interactive system that can deal with differences in user responses. The basic principle behind this design is that the simplest interaction options are usually the most useful, and that they can be implemented without extensive hardware modifications, but only using a few simple and reconfigurable heuristics.

3. IMPLEMENTATION

The developed system is based around two main platforms - the sonification system functions on a *raspberry pi*, while the sensor acquisition system is based on an *Arduino* family microprocessor system. In some prototypes the sensors are wireless and are separated by an RF link, meaning the sensor can be physically located on or in a piece of furniture or other position, while the *raspberry pi* is centrally located with an associated power cable, loudspeaker and wi-fi internet access.

3.1. Sensors and Reactions

The sensors used with this system will be designed to activate simple interactions in the environment. The interactions we use may include actions such as:

- turning on a light;
- opening a drawer;
- opening a door;
- crossing a threshold;
- making noise.

These interactions are natural and usually necessary to achieve daily tasks, and can be associated with an action that is not only common, but also predictable and timely. For instance, turning on a light is not only usually happen when the room is to be used, but is associated with, and likely precedes the room's usage for particular purposes. If those purposes are known, appropriate data can be presented to fit with the room's usage. Each of these interactions and responses are simple in isolation - but the modular nature of the system described means there will be a level of customisation afforded to the sonification user to allow them to incorporate the presentation of data into their lives at a fundamental level.

Importantly though, this system will not rely on visual graphs or sonifications presented and interacted with using a mobile phone or similar equipment. This is for a number of reasons - the current trend towards providing control over in-home systems via mobile phones assumes that users use their mobile phone in predictable and consistent manners. Most importantly, though, using any mobile phone is a break from a type of interruption-free interaction 'flow' that may be being aimed for through exploiting everyday interaction, and therefore it is not a relevant device to the present discussion.

3.2. Software and Hardware

The Arduino is connected to the raspberry pi system by way of the onboard GPIO headers, making for a compact sandwich approximately 8.5 by 5.5 cms in size. The arduino system has multiple digital connections as well as analogue to digital convertors (ADCs) which can be used to measure voltages from analogue sensors of various types. Code is 'flashed' onto the arduino microprocessor which performs simple tasks such as reading the ADCs and forwarding the result to the serial port for use, or sending the data via RF to the main sonification system. This architecture, keeping the sensor wireless, helps with rapid prototyping to exploit new sonifications.

The *raspberry pi*, while very small, contains enough computing power to interactively process synthesis for sonification purposes. A complete computing system, rather than only a microprocessor, allows the use of multiple modular layers of software to perform the sonification tasks and to access web-based data and systems. This single board computer provides a basic analogue audio output and an ALSA audio driver, as well as an HDMI output (not used in this project). The computer runs a stripped down version of the Debian Linux Operating System designed for the chipset used, a Broadcom BCM2835. For storage, an SD card inserted in the system's card reader providing ample space for audio recording and playback. Quite a few well-known audio programming languages can be easily installed for use on the system, including CSound and Pure Data, as well as general purpose scripting languages such as Python, and statistics languages such as R [18].

The main drawback of past investigations of ambient sonification have been that they rely on a computer to sonify the data, but a general-purpose computer is usually crucial for other tasks, and after the prototype has been evaluated for a relatively short time, the system is disassembled to be re-used for other purposes. Using an expensive and bulky computer for sonification is not an approach that is of lasting interest to users. Recent alternatives have often used the computing power of smartphones to take this role - but again, their practical use precludes leaving them in particular locations for long periods.

Modern system-on-chip computing systems (eg. Gumstix, BeagleBone, Raspberry Pi) are now such low-cost systems (approx. $35) that ambient computing is likely to become more and more commonplace. Therefore, the context that previous research has shown sonification excels for – background monitoring of data sources – is also becoming cheaper and easier to implement.

A further implementation consideration is battery life – despite their usefulness, it is still largely impractical to use any computer system (including a mobile phone) with a battery for any lengthy period of time, due to their high current draw. However, arduino systems excel at low-power usage scenarios, and can be extended by exploiting their 'sleep' function to lower the power usage even further. Therefore, for a reasonable battery life to be obtained, while the sensors can be battery-powered and only require periodic battery changes, the sonification system itself still needs to be mains powered, and therefore centrally located. Also, different arduino implementations have different power usages, and some arduino systems designed for wearable computing can use as little as 3 mA. By comparison

4. PROTOTYPES

This next section will demonstrate several prototypes. Each prototype demonstrates the above framework in use and is based on exploring a particular context.

4.1. Prototype One: Weather Sonification

The first prototype is based around presenting weather data in an unobtrusive way, with the purposes of ensuring that a user is informed about the weather prediction before they make decisions about the day's clothing choice.

The prototype uses the disturbance model; when a sensor is disturbed a sound (a sonification) is played in response. It follows that the sensor used controls not just the type of interaction used to trigger the sonification, but inherently also the notification level of the system. A sensor that responds to movement in a well-used space would obviously trigger the sonification far too much, while using an everyday interaction that only occurs once per day at a precise time will mean the notification level is significantly reduced.

A solution is to attach a sensor to a part of a wardrobe, that is used at precisely the same time everyday. A light sensor can be placed close to the front corner of the drawer, and when opened will result in a single high value per day when the drawer is used.

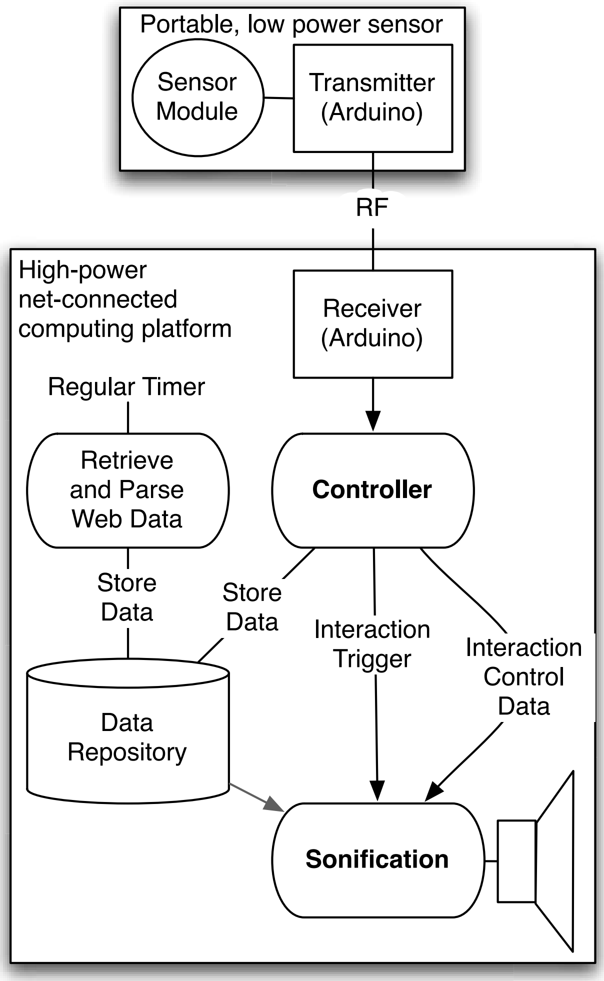

Figure 2: The software framework uses a number of technologies in two separate devices to obtain sensor information, transmit it to the main system, and sonify the data there.

This results in two benefits, the notifications occur at the appropriate time (when the user is selecting clothes), and interacting with the wardrobe becomes useful for repeating the sound.

In terms of sonification algorithm this is a relatively straightfoward method. The sonification algorithm is specified using Brown's `playitbyr` package for R, interfacing with CSound [19]. The sonification algorithm itself translates temperature data from 0-48 degrees Celsius to notes within an octave (0-12 semitones). To provide context a constant tone at the tonic is provided, meaning the sonification presents chords rather than single notes; the contextless single notes are replaced with recognisable intervals. This results in a major second or major third representing temperatures between 8 and 16 degrees, a perfect fifth interval (7 semitones) representing a warm 28 degrees. Larger intervals of a major sixth or seventh represent very hot weather. While this means that a single negative value chord may be mistaken for its positive value reflection, in practise it is unlikely an entire contour could be mistaken.

The sonification is all produced on the raspberry pi board, with both the R software and CSound software installed on it. The weather data is obtained from the 'weather underground' service[1], and is parsed using the R XML parser.

4.2. Prototype Two: Door Opening Times

The second prototype presents the user with information about when a door has opened over the last few days. The system is designed to assist users in making inferences about patterns of behaviour, based on reflection on data sonifications. A history of door opening may be used to estimate when a user leaves and enters a residence, for instance.

As the door opens, a digital sensor placed on the door records a change in the door angle. This change causes the sensor to transmit this data, which is then recorded and time tagged. An auditory dotplot [20] can then be played to represent the times the door angle changed. With enough usage data stored, this sonification would be expected to elucidate a pattern based on the timing of the door usage over the past week showing weekend usage differing from weekday, and other patterns of change. Through sonifications of this nature a user has the opportunity to reflect on their daily behaviour, possibly developing new strategies and ideas about what they do each day.

4.3. Prototype Three: Drawer Opening

The third prototype is based around developing an understanding of the use of everyday interaction as a method for exploring the data along a particular axis. An ultrasonic distance sensor attached to the back of a desk drawer provides information about how far open the drawer is, which can be used to step through a dataset of information along a particular axis.

The dataset used is a simple probability of precipitation dataset (again sourced from 'weather underground'), with a value from 0-100 representing the probability of any precipitation at that particular time during the day. The sonification used for this responses is simple – the probability value is mapped to the gain of a simple noise band or rain recording representing rain. A non-visual cue to the time axis is presented as a series of short (¡100ms) sounds to mark points of the day such as 6am, 12noon and 6pm.

On most days this sonification will stay mostly silent. However, on days where rain is predicted the sonification will sound as the drawer is opened (which would be every morning). On closer inspection the user can move through the data set and get a more accurate idea on when the rain is likely to occur. If they wish to give themselves a visual aid they can make marks or even a scale on the side of the drawer to help them interpret the time axis with precision, but alternatively they can use the non-visual cues to the time axis. When the drawer is more or less closed, and the time axis value is less than '3am', the sonification is silent.

4.4. Prototype Four: Light Sensor

The fourth prototype is slightly more playful than previous prototypes, but aims to give the user method of perceiving the recent usage history of illumination in rooms.

A simple light sensor (light sensitive resistor) is positioned in a room, and samples the illumination over time. This illumination data is recorded and time-tagged for a period of five days or more.

[1] http://www.wunderground.com/


(a)

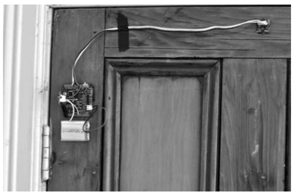
(b)

Figure 3: Two examples of the prototype sensor systems activating everyday interactions.

This history is then wrapped around to make five parallel dimensions of data, synchronised to the time of day they were recorded. Each of these is sonified using a simple algorithm, mapping the sensor output to the gain of a tone. The pitch of the tone is related to the day the data was recorded on, with the most recent day having the highest pitch, and the others descending along a pentatonic scale.

5. DISCUSSION

This set of implementations of prototype ambient sonification systems has brought many design challenges and findings to light. These are summarised below.

5.1. Design Patterns

The use of an ambient sonification systems with sensors for interactions allows the use of many alternative designs, but some of them emerge as appropriate patterns for sonification design.

The first approach we could characterise as 'Windchimes', and refers to a process by which the user passes into a space and the sonification acts as an ambient sound source, the qualities of which transmit the necessary information. A second pattern, requiring more direct interaction, could be described as a 'Double-take', and refers to the way in which the user may thoughtlessly interact with a piece of furniture or household item, that may respond to their interaction, causing them to repeat the interaction to re-assess the sound – a double-take. A third pattern could be described as 'Open and unfold'. Opening a door has an important acoustic correlate, in that a door opening usually progressively increases the sound egress from a room, and allows a listener to hear more of what is going on inside that room. Similarly, the opening of a drawer has a symbolic meaning, the possibility of what is contained in the drawer, alongside the single axis of movement of the drawer, give the user a strong metaphor to transfer to the representation that is partnered with this action. The data dimension that is associated to this axis is likely to be similar to the one that is associated with time, but the interaction affords reversal and exploration of the axis, rather than just single, or repeated listenings.

5.2. Presentation Format

Taxonomies of ambient computing use the term 'temporal gradient' to describe how much, and the way in which, the information is represented. This is an essential component to the sonification prototypes we discuss here.

Some approaches have been highlighted for sonifying data of a temporal nature in an ambient context, specifically to do with how to treat the temporal axis. The first method is to use a sensor disturbance to begin a traditional sonification - to use the sensor as a push-button switch, where if the threshold is exceeded the sonification begins and plays through a predetermined time course. With this method it is crucial that once the sonification has been begun it is likely to be easiest to play it all the way through.

The second is to treat the disturbance of a sensor as a basis for beginning an ambient sound that represents characteristics with no particular relationship between the sonification time axis and the information time axis. The third is to explore interactions that occur naturally that can be exploited to provide the user with an axis of control - such as the opening of a drawer, or the angle of opening of a door.

5.3. Scales and Context

A significant issue that exists with the creation of an ambient system is how to provide context and scaling information without the use of supporting graphs, or pre-existing explanations of the mapping between the sonification and the information being represented.

Different situations provide different problems. If the system provides immediate feedback in response to an interaction, then the system cannot provide a preceding sound to act as a scale. However, if the system has a period of latency between the sensor disturbance and the sonification, it can be easily used to provide a preceding 'auditory signpost' for the listener so that they can interpret the sonification.

Elegant designs, however, may avoid the need for extra sounds to be temporally interjected and may focus on developing sounds that immediately betray their context and interpretation.

5.4. Ambience?

Many ambient computing systems do not rely on interaction from users, but work automatically at predetermined 'notification levels'. This study has explored the use of sensors to activate everyday interactions for ambient computing. This has the advantage that a system design of this nature should not suffer the 'cuckoo clock' issue, where the unexpected interjections of the system result in its deactivation after only a short period of time. This is of especially high importance for a sonification system, as opposed to an ambient computing system that may, for instance, change a light's colour to signify a change in some type for data.

By exploiting actions that are predictable, unintended sonifications can at least be anticipated by users, and they can time their interactions to fit with their expected acoustic conditions (e.g. avoid opening a drawer while talking). Coupled with appropriate designs incorporating simple, short sounds for sonifications, the sonifications can remain effective when they are needed, but silent otherwise.

5.5. Evaluation

Evaluation with users is always important in the design of new systems, but in this preliminary work we have chosen to focus on developing an understanding of the design approaches and implementation challenges. Further work to extend the system can naturally also encompass evaluation with users. Nevertheless, in some ways evaluation methods may face challenges in being helpful in this context - this work seeks to make a broad range of ambient sonifications possible and easily achievable, rather than designing a particular ambient sonification for a well-specified situation. The aim of this study is to 'move the goalposts' of design possibilities by opening up a range of alternate, playful interaction possibilities.

Further work to develop more sonifications and everyday interactions, will extend the usefulness and flexibility of this approach. Exploring the embedding of sensors *within* objects is another fruitful area for extension of the interactions.

6. CONCLUSION

This work has investigated the design and implementation of an ambient sonification system that uses sensors to activate interactions in a domestic environment. This paper presents an initial concept of how a framework like this might be implemented in a flexible way. The main issues dealt with are

The process that may be used to describe the interaction methods used was explored. We have presented a number of simple prototypes and have attempted to discuss what the differing needs and approaches are when sonifying data in an ambient context, rather than sonifying data for focused data analysis, or using visualisation for ambient data representation.

The opportunity that this work embodies is that ambient sonifications of data may be designed and built by many different practitioners, or even a technically well-versed end-user, rather than by a manufacturer or product designer. This flexibility of purpose has been crucial in the acceptance of many new ideas in technological fields.

The continued extension of this project relies on the community development and extension of the implemented systems, and to further this work the code and general instructions has been made available[2].

7. ACKNOWLEDGEMENTS

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