LISTENING TO PEOPLE, OBJECTS AND INTERACTIONS

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ABSTRACT

As a pedestrian or motorist moves through a busy modern city, an enormous amount of visual filtering needs to take place in order that they can make sense of the huge amount of constantly changing detail being presented to them. Numerous peripheral details must be suppressed in order that basic tasks can be accomplished such as navigating, avoiding hazards, obtaining a general impression of their surroundings and taking in what is going on around them. Almost in contrast, we often give relatively low priority to the huge amount of information which can be obtained by listening to our surroundings. Furthermore, it is remarkable how much information can sometimes be obtained through listening, sometimes only for a very short time, to the specific interactions and behaviour of people and objects. This paper examines a range of situations which exemplify the spectrum of ways in which we experience the world through listening, and relates these experiences to what we are learning from research into interactive auditory displays and data sonification. The question to be examined is "what can we take into the research arena of auditory displays from our every day experiences of listening?"

1. INTRODUCTION

As a some time owner of a guide dog, I have been surprised, not to say amused, by the number of times I have been asked how a dog is able to cope with the decisions required to get safely from A to B in a busy city environment. "How does he know where you want to go?" and "how does she know when its safe to cross?" are typical of the questions put by people unfamiliar with how the partnership between a visually impaired person and a guide dog operates. The truth of course is that a guide dog virtually never has to deal with this kind of decision-making, or at leased not at the level intended by people asking these questions. The reality is that it is the human side of the partnership that makes the key decisions on both of these aspects of navigation; the role of the dog is essentially secondary. The human decides what route is to be walked, including which roads are to be crossed and when. The dog plays a backup role in that if, from previously walking the route, it knows the way, then it might take the initiative and guide the human in a very positive manner. However this only works in so far as both parties are agreed on the route to be traveled, there can and often will be times of disagreement, particularly in the case of a trip to the vets, or where the local butcher's shop has to be bypassed rather than visited! When it comes to the crossings of roads, the role of the dog is most definitely secondary; it is the human, first and last, who determines the time at which a road can be crossed. The role of the dog, instilled during training, is simply to go when asked, or, not to go if it perceives danger (through traffic or obstacles) not perceived by the human. Incidentally, this training to stop if asked to cross in the face of oncoming traffic, is supposed to be re-enforced periodically by the human, by asking the dog deliberately to go when there is traffic coming, much to the bemusement of the oncoming driver.

So route navigation and road crossing is achieved by totally blind pedestrians, with or without the use of a dog, through a combination of developing a mental map of a route, asking directions and listening to sounds in the environment. Routinely blind pedestrians cross roads basing decisions on when to cross on hearing alone. To quote Massof [1], "A highly skilled blind pedestrian can approach an intersection, listen to the traffic, and on the basis of auditory information alone, judge the number and spatial layout of intersecting streets, the width of the street, the number of lanes of traffic in each direction, the presence of pedestrian islands or medians, whether or not the intersection is signalized, the nature of the signalization, if there are turning vehicles, and the location of the street crossing destination." [2-3].

This is just one example of a way in which hearing can be used to achieve something, which most people would probably not expect it could be used to do. We shall return later in the paper to the impact that new technology is having particularly on the mental map formation and route navigation tasks.

2. LISTENING TO PEOPLE

2.1. Speech

When someone speaks, even setting aside the actual words that are being spoken, one can often obtain a great deal of tentative information about the individual, even within the first 2-3 seconds of the utterance. The inherent characteristics of sound, volume, pitch, timbre, prosody, attack, decay, tempo etc are all carriers of messages about the original source of the sound. In the case of humans, usually it is possible to know their gender (assuming they are unseen), often something of their mood, the level of confidence they have in their given context, the pace of their discourse, their attitude towards the person or people they are speaking to. From their accent it is often possible to obtain some idea of where they are from, occasionally with considerable accuracy, as well as their ethnic origin and sometimes their history. When you then take into account their actual choice of words, it is often possible to glean something about their familiarity with the language they are using, their range of vocabulary in that language and sometimes something about their education. All of this comes within a very few seconds of them starting to talk. While its a very unwise person who fails to reserve judgment and wait for confirmations as time evolves of all of these things, its remarkable how quickly we are provided with strong clues towards a starting point about the background, mood and general disposition of someone simply through their speaking. While it would be again unwise to place too much reliance on any one of these vocal characteristics, one subconsciously looks for confirmatory messages, consistencies across the range of indicators that add up to stronger evidence of someone's origins and background.

However, the sands on which these partial judgments are made are certainly shifting. The typical backgrounds of individuals are becoming much less homogenous. We live today much more in the era of the hybrid, individuals who have traveled relatively widely, have international experience, and who have lived for significant periods in different locations on a national and increasingly an international basis. In terms of the design of auditory displays and interactive sonification systems, we should consider carefully what elements might be included in such systems that can leverage the ability we have as humans to gather so much from such relatively short but information rich audio messages.

2.2. Non-speech human sound and communications

In addition to speech, we all give rise to a wide variety of sounds, which are either self made or brought about through our interactions with objects. These equally provide the attentive listener with a rich quantity of information concerning our presence, current activities and mood. Humming, whistling, opening and closing doors, interacting with all manner of household or work-based objects emit sounds which, when taken together can almost be considered as an auditory persona, an audio presence indicative of the interactions, moods and activities of an individual. Some of us for example have noisy auditory personas, announcing our presence to anyone within hearing range, while others deliberately attenuate sounds, which we feel, may be disturbing or intrusive to others. Many of our interactions with objects bare our own very characteristic signatures, the way we knock on doors, play instruments, type on keyboards, whistle and even in some cases the way we breathe.

An interesting example of research which exploits typical incidental sounds made by humans is that of Kainulainen, et al. [4], who described an application to support peoples awareness of each others presence in an office environment using embedded loud speakers. They used unobtrusive, calming and continuous soundscapes such as bird song and people walking to convey the information without risking cognitive overload of workers.

An extremely important, inaudible (or virtually so) area of communications between human beings involves that of non-verbal communications (NVCs). A teacher can tell so much from the NVCs from a class, all parties seek to infer a great deal from the body postures adopted and gestures made during interviews, so many initial communications are made through eye contact. This is another whole realm of interactions, which are pivotal in the formation of initial impressions and the way in which those impressions are or are not confirmed. NVCs are of course as susceptible to the same kind of stereotyping as other communications mentioned earlier. At Queen Mary we are examining issues relating to the mapping of such NVCs into audio, primarily for use by visually impaired people. Correct body posture and the use of gestures in job interviews, backchannel communications (as in teaching), noisy club environments and locating an individual in a crowd are among the numerous application areas where the sonification of NVCs may play a valuable role.

3. LISTENING TO OBJECTS

As pointed out by Hunt and Hermann in their paper on Interactive Sonification in the first of this series of workshops [5], we make substantial use of the every day sounds of objects to monitor their state and to carry out numerous tasks. Home appliances such as washing machines, car engines, and many other every day objects produce sounds which we use routinely, and often semi-consciously, to monitor and trigger actions. Taking the example of a kettle, depending on the design, one may be able to tell how far it is from boiling, of course whether it is working at all, kettle size, and to some extent its general internal state of repair/age. However, many devices exhibit what might be seen as missed opportunities for conveying their current state in audio. For example, the steady hum of a microwave gives no idea of its current setting, or how long left it has to run before stopping, far less still the state of the food inside. The sound of a computer's hard disk in operation or otherwise is sometimes useful to computer users as confirmation or not that things are working as expected. This is quite often particularly useful to visually impaired computer users, when dealing with a problem where screen-reading software has temporarily or permanently failed, or prior to the screen reader being launched where there are problems in booting the machine. One might detect for example that the system has initiated a scan of the disk, as compared to the sound of it going through its usual boot sequence, or iterating over one or more processes from which it is not able to progress.

4. LISTENING FOR NAVIGATION

As touched on in the introduction, nowhere can listening play more important a role than when traveling. There are now several devices and research projects, which seek to compliment the natural listening skills of visually impaired travelers to provide additional information for navigation. Before briefly exploring some of these, it is perhaps worth taking a step back to examine the context in to which these new technologies are being introduced.

It is sometimes said that the first dictate when considering an intervention in medicine, is first of all do no harm. When introducing new technology into situations where individuals are making decisions about navigating the environment, crossing roads, avoiding obstacles etc. Then considerable care needs to be taken firstly to ensure that the natural ability of the user is not significantly impeded by the introduction of the technology. This is particularly the case when for example in the use of audio; the technology makes use of some of the available bandwidth that is already being used for the natural listening process. Overall we can say that the net good that must be achieved by such a navigation aid must exceed anything it detracts from the users natural faculties in comprehending the environment. In reality of course such measures are hard to quantify, but the net loss or gain of introducing additional mobility aids must be assessed through a combination of quantitative and qualitative (subjective user views) measures obtained from careful usability evaluations. An important contribution in this area is that of Walker [6], who demonstrated the effectiveness of bone conduction headphones for delivering auditory information during wayfinding tasks undertaken by visually impaired users. This work opened up increased possibilities for auditory displays in wayfinding tasks for many visually impaired users whose preference would be to avoid wearing conventional headphones while navigating the environment, because of their reduced ability to hear environmental sounds. Kainulainen et al [7] showed how non-speech audio can be used to complement speech-based and graphical route information in a mobile public transport guidance application. In addition to guiding users with speech, auditory icons were employed to describe route information, such as available transport options and temporal information. They also used Soundmarks, the auditory equivalent of visual landmarks unique to a given location, to identify spatial points of interest, and provide landscape and landmark context for navigation. The auditory icons were used in complement to visual and speech-based guidance to support users "as a less intrusive, awareness supporting information source".

Many of the sounds in the environment, including those intended specifically to assist both sighted and visually impaired travelers, are disappointing in the level of semantics provided. Take as an example the simple auditory traffic beacon crossing sound used in the UK, which consists of a series of same pitch beeps to indicate that it is clear to cross. On arriving at such a crossing when it is beeping, there is no indication available of how much longer it is going to remain safe to cross. While acknowledging that it is necessary to keep the messages transmitted by such devices essentially simple, given the wide range of sound parameters available for modifying the beacon sound, such as timbre, pitch and tempo, it seems a lossed opportunity not to attempt to include at leased some level of higher semantics into the audio signal. Similar opportunities would appear to be available in the sounds of vehicle horns. For example, Russo [8] assessed methods of increasing the effectiveness of train horns without increasing intensity, paying special attention to the problem of masking by car noise.

Their Findings suggested that train horns could be made more effective by ensuring substantial mid-frequency energy, shifting the spectral centroid higher, and increasing musical dissonance. There are certainly other opportunities for using good audio design to assist visually impaired and possibly sighted pedestrians of the approaching presence of inherently quiet vehicles such as bykes and electric cars. A particularly notable paper in this area was that of Avanzini et al's work [9] on designing sounds for the high tide warning system in Venice, which had to warn of high tides across the city and be intuitively meaningful to a large body of users.

As an example of how quickly the technology is advancing in this, as in other areas, in a keynote paper at ICAD'2003 [10], in the context of sensory substitution, Loomis wrote the following: "If the sensory bandwidth of the substituting sense (or senses) is grossly inadequate, it is simply not possible to carry out the desired function. For example, the informational demands of driving a car are not likely to be met through a combination of audition and touch.". However, on July the 15th 2009, the TechRadar site reported that researchers from Virginia Tech's Robotics and Mechanisms Laboratory had succeeded in creating a "retrofitted four-wheel dirt buggy" in which a blind driver can turn the steering wheel, stop and accelerate by following data from an on-board computer that uses sensory information from a laser range finder which provides information about obstacles and road turnings etc. The vehicle also incorporates non-visual interface technologies including a vibrating vest for feedback on speed, a click counter steering wheel with audio cues, spoken commands for directional feedback, and a tactile map interface that uses compressed air to provide information about the road and obstacles surrounding the vehicle [11].

Symptomatic of the growing interest in the use of audio and other forms of non-visual feedback in the context of navigation is the introduction of the series of workshops on "Multimodal Location Based Techniques for Extreme Navigation" [12], the first of which will take place in conjunction with Pervasive 2010, Helsinki, Finland on May the 17th, 2010. The series will consider how non-visual sensory channels, such as audition and touch, can be used to communicate information to people involved in activities such as running, rock-climbing and cycling, where navigational and geographical information is needed, but where the visual modality is unsuitable, as well as to user groups such as the visually impaired and the emergency services, who also require non-visual access to geo-data.

5. GESTURES AND SONIFICATION

A good deal of work has been reported both in the ISon workshop and ICAD conference series into the audio representation of gestures and in the role of gestures in controlling interactive sonifications.

5.1. Sonification of Gestures

Beilharz [13] proposed a framework for gestural interaction with information sonification in order to both monitor data aurally and to interact with, transform and modify the source data. Fox et al. [14] described SoniMime, a system for the sonification of hand motion. Among SoniMime's applications is the use of auditory feedback to refine motor skills in a wide variety of tasks. The primary sonification method employed involved mapping movement to timbre parameters. They explored the application of the tristimulus timbre model for the sonification of gestural data, working toward assisting a user to learn a particular motion or gesture with minimal deviation. Midgley et al. [15] described increased user satisfaction and comprehension when using auditory-enhanced gestures over the non-enhanced gestures for mouse interactions with the Firefox web browser. The results of these and related works give some indicators as to how one might progress with the sonification of NVCs refered to in section 2.2, although the discretion required to present NVCs to visually impaired people unobtrusively indicates that, in some situations at leased, a haptic rather an auditory display would be preferable.

Murphy et al [16-18] described a multimodal browser plug-in, with audio and haptic feedback, developed to explore how basic concepts in spatial navigation can be conveyed to web users with visual impairments. A second version of the application was evaluated within a collaborative setting, to explore whether it is possible to use the approach in a working environment between visually impaired and sighted Internet users. Using the multimodal cues, users were able to successfully navigate a sequence of screens with directions from a sighted user.

In the realm of physiotherapy, Pauletto et al [19] have investigated the sonification of Electromyography (EMG) data (data on the electric potential of muscle cells), while Vogt et al. [20] used synthesised acoustic feedback to improve awareness of human body movements by physiotherapy patients.

There is a growing body of work describing the sonification of gestures in sports applications. Effenberg has authored a number of interesting studies exploring the effect on performance of the sonification of movements in sports and the relation between the auditory perception of such movements and their integration with data gathered from other senses [21, 22]. Höner et al. [23] used an auditory display to support and extend the visual analysis of tactics in handball, using the display to identify players who deviated from a nominal tactical position, along with their degree of deviation. Schaffert et al [24] presented a sound design for the optimization of sport movements in rowing. The motion of the boat was sonified in order to make audible the measured differences in intensity between several different steps in the performance of each rowing stroke. Hummul et al. [25] describes a variety of sonification approaches to provide real-time auditory feedback about the rolling motion of a German wheel to a performer who is carrying out acrobatic moves on it.

A considerable Strength of many of these applications is the immediacy of the feedback provided that can be used to inform a correction or alteration in the feedforward component of the control loop. We can anticipate that the use of non-traditional forms of feedback, in particular haptics and audio, will continue to play a growing role in systems incorporating a man-machine control loop of this kind.

It is possible to imagine how audio and/or haptic feedback may increasingly be used to play a role in sports training and even in competitive game situations. For example players (sighted or visually impaired) in team sports could be provided with mechanisms to enhance their awareness (for example of team mates or opponents currently out of their field of view, or of instructions from coaches). At a time when disabled sports is growing in its level of sophistication and coverage (for example see www.blind2010.com for coverage of the forthcoming blind soccer world cup), it is easy to imagine how their may be a growing demand for multimodal approaches to the representation of different coaching and live game/event scenarios.

5.2. Gestures as the controllers of sonifications

Bovermann et al. [26] and Hermann [27, 28] described the scanning of high-dimensional data distributions such as EEG time series by means of a physical object in the hand of the user. In the sonification model, the user is immersed in a 3D space of invisible but acoustically active objects, which can be excited by the user. They describe how the use of a physical controlling object to explore complex data provides "a strong metaphor for understanding and relating feedback sounds in response to the user's own activity, position and orientation." A particularly compelling example of gesture as the controller of sonification was provided by Williamson et al. [29], who described an excitation interface for displaying data on mobile devices. Accelerometers are used to sense the gestures of a user shaking the mobile device, in response to which the interface provides a rapid semantic overview of the contents of the SMS inbox.

Stockman et al. [30] have identified a number of ways in which current screen readers have a negative impact on the way that web pages are presented to users. These issues, largely related to spatial layout of the page and obtaining overview information, become more acute in situations where it is required to work collaboratively with one or more sighted users, at which point mutual awareness becomes a further important factor. The approach developed by Murphy et al [16-18] goes some way to addressing some of these issues. Gestural input appears to be a promising way forward for visually impaired users to navigate relatively large scale interfaces, e.g. large documents or document collections, large web sites, detailed maps etc. with appropriate auditory or haptic feedback to confirm which gesture was actually executed (particularly for inexperienced users) and the resulting state of the display.

6. ECHOLOCATION

Echolocation is a means of hearing objects that are around you, even if they are not moving or interacting with other objects. It is a generally poorly understood phenomenon, even though many visually impaired people, and possibly sighted people also, make routine use of it every day. Recent work has provided us with clear scientific evidence that the phenomenon is based on sounds as they are reflected from objects, predominantly, but not entirely, these sounds being created by the listener, Neuhoff [31]. For example, as one walks down the street, it is possible to hear objects as one passes them. Examples of typical objects one can hear in this way include lamp posts, parked vehicles, trees, as well as changes between shop windows and shop entrances, walls, etc. It also seems possible to hear moving objects in this way, though because these usually will be emitting sounds of their own, its not easy to dissociate what is heard due to echolocation and what is heard from the sounds produced by the motion of the object.

Echolocation, not surprisingly, appears to play a significant role in blind sport, particularly in relatively static situations, such as in blind soccer when waiting for a corner kick or throw-in, where one might use echolocation to sense where other players are and to find free space. In more dynamic situations, for example when the ball is in play, the relatively sensitive nature of the echolocation phenomenon seems to be masked by the normal sounds of the game. One can improve the results of echolocation by making more sound, for example it is easier to echolocate a wall you are approaching if you are wearing hard shoes on a firm surface rather than wearing socks and walking on a carpet, Neuhoff [31]. I have come across instances where blind people have deliberately made clicking noises with their tongue to improve their chances of locating the entrance to a doorway in situations where a building has a wide frontage. Neuhoff [31] relates a case study of an 11-year old blind cyclist who used echolocation to avoid obstacles on a given course, and I have myself used echolocation as a child and come across plenty of other instances of blind children, when riding bikes or small trucks, employing echolocation to avoid obstacles and knowing when to steer round corners in a familiar setting. As an adult I regularly use echolocation as a means of knowing when to turn corners (because the echolocation of a wall has ceased) in underground stations and in other situations. The phenomenon seems to work best for me in relatively familiar surroundings. It is not that it disappears of course when I am somewhere unfamiliar, its simply that in those circumstances one typically looks for confirmatory evidence of what echolocation may appear to be telling you, for example before making a turn. Most studies of echolocation have involved either visually impaired participants or bats, but there is no reason to think it cannot be used equally by sighted people, its just that in most circumstances sight is by far the dominant means of perceiving objects in the environment. It is an intriguing thought that under some circumstances we might all benefit by trying to cultivate and make better use of this means of perception, in both real and virtual environments.

7. CONCLUSIONS

Human hearing and cognition is capable of incredibly rapid assimilation of information on a number of levels simultaneously, as exemplified by what we can infer from a few seconds of human speech. Convincing virtual reality systems which represent multiple virtual beings are likely to exploit this potential, as well as providing a rich representation of all the non-speech human sounds that are present in any realistic human environment. The amount we can discern from careful listening to the sounds emitted by every day objects is not to be underestimated. Frequently such sounds can be exploited in a diagnostic or monitoring role, in situations where sight of the interacting objects creating the sound is difficult, inappropriate or impossible.

While we have examples of worthwhile and imaginative uses of audio that are of value to many people when navigating the environment, there are also substantial opportunities for improving the level of semantics conveyed by vehicles or indicators of traffic activity. The choice of output modes for such displays is a key issue. For example haptic indicators are often employed in situations where road-crossing beacons are so close together that, if audio was to be used, pedestrians might be confused by signals from nearby crossings, rather than the one they are currently using. In other situations the choice of mode is less clear. In general, multiple output modes are desirable to cater for sighted, hearing and visually impaired pedestrians, but this is very rarely encountered in practice.

Recent work on the sonification of gestures has brought about valuable progress in a number of application areas, notably in the medical domain in the learning or correcting of movements by patients undergoing physiotherapy, or with severe difficulties in controlling limb movements.

Interesting possibilities exist to build on the work already done in the area of sports tactics and coaching, in particular by examining the effectiveness of haptic and/or auditory enhanced awareness in real-time, for both training and competitive game situations, for both mainstream and disabled sports. There is little doubt that numerous other application areas exist, such as supporting orientation and navigation in unusual and/or unfamiliar environments.

The use of gestures as a means of affording the analysis of data, for example in multiple dimensions, often leads to an intuitive style of interaction which encourages data exploration and multiple perspective taking. Interesting issues exist in supporting this mode of data investigation in a collaborative setting, and for example extending it to support data manipulation while maintaining mutual awareness, including the possibility of different users employing different input/output modes from one another. An example application area might be where a teacher takes a group of students through a series of detailed data analysis and manipulation tasks, where different members of the group employ, through necessity or choice, different modes of interaction.

Overall it is clear that we are fortunate in possessing extraordinary capacities to perceive and interpret information in the numerous forms it presents itself, either in the real or virtual world. We are still, I believe, in the very early days of understanding how best to design systems that remotely mirror that human capacity. We are similarly at a relatively early stage in fully understanding the interplay of audition, touch and gesture, but we are beginning to uncover the exciting potential and enhanced human capabilities that can be provided through the effective combination of these modes of interaction.

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