VisAural: A Wearable Sound-Localisation Device for People with Impaired Hearing

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ABSTRACT

Although our sense of hearing, smell, and vision allow us to perceive things at a distance, the detection of many day-to-day events relies exclusively on our hearing. For example, finding a ringing phone lost in a sofa, hearing a child cry in another room, and use of a car alarm to locate a vehicle in a car park. However, individuals with total or partial hearing loss have difficulty detecting the audible signals in these situations. We have developed VisAural, a system that converts audible signals into visual cues. Using an array of head-mounted microphones, VisAural detects the direction of a sound, and places LEDs at the periphery of the user's visual field to guide them to the source of the sound. We tested VisAural with nine people with hearing impairments and found that this approach holds great promise but needs to be made more responsive before it can be truly helpful.

Categories and Subject Descriptors

K.4.2 [**Social Issues**]: Assistive technologies for persons with disabilities

Keywords

Hearing impairments; Sound localisation

1. INTRODUCTION

For many people, the ability to hear allows them to detect everyday events such as a misplaced phone ringing, or a baby crying. But for almost 17% of the UK population who have a hearing impairment [6], audible signals used to detect these events are not available. Hearing aids have been developed to help overcome challenges of general deafness, but uptake is low (only 14%)[6], and it has been demonstrated that they do not preserve spatial information, impeding sound localisation [2]. The Positional Ripples Display [4] partially addresses this problem, but requires knowledge of the deployment location and is therefore not easily adaptable. Similar work on developing a peripheral display of sound was undertaken in 2007 [1], however this solution was not portable.

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These pieces of work demonstrate the capability to aid individuals through visualisation of audio; and both underline the value of using abstract visualisations to do so.

To address these problems, we have developed a wearable device that detects sounds in any environment, converting sound information into directional visual cues to inform the user of the direction of sounds. By using the visual cues from our device, people with hearing impairments should be able to interactively identify the location of sounds in their environment. The visual system is a suitable alternative to the auditory system as localising sounds typically uses visual search. Furthermore, out of all our senses, vision is the most synonymous with hearing; both are used to construct spatial understanding of our environment, both enable sensing at a distance, and it is arguable that they are the two dominant means by which humans develop an understanding of the world. A similar device to our system was developed [5], but this work focussed purely on the engineering task of creating the device, not on evaluating its effectiveness for helping people with hearing impairment.

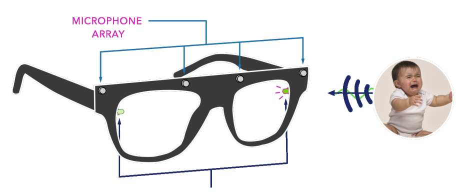

Figure 1: Device detects the baby's cry to the left of the user, lighting an LED in their left peripheral vision - signalling the sound is to their left.

2. VISAURAL

For input, VisAural uses an array of microphones mounted on a pair of eyeglasses (Figure 2). For output, LEDs are fixed on the left and right of the eyeglass frame (Figure 1) . Signals from the microphones are processed through a unit comprised of modified commodity hardware and a laptop computer. Sound is sampled from each of the four microphones and stored in a buffer every 0.2 seconds. The data is checked to ensure it has values above the microphone array's noise threshold to determine that there is a loud enough sound present. Using a delay-and-sum beamforming algorithm [3], the delay between each microphone and a common reference point (midpoint of array) is computed for each potential angle a sound can arrive from. In order to reduce computation, the system only checks for sounds arriving from either the left or the right at 15°, 30°, 45°, 60°, 90°. The resulting delay relates to how much longer it takes for a sound to arrive to the reference point versus the adjacent microphone. Each signal is delayed by the number of samples required and summed together. This results in 10 signals (five angles each on the left and the right), one for each potential direction. These signals are compared and the signal with the largest gain is taken to represent the direction of the sound.

When no sound is detected, both LEDs are off. If the loudest post-threshold sound is detected on the left side of the head, then the left LED is activated, signalling the user to turn towards the left. If the loudest sound is detected on the right, then the right LED is activated. When the left and right have roughly equal volumes, both LEDs activate telling the user that the origin of the sound lies within their visual field. In this manner, the user will be able to "hone in" on the source of the sound.

Figure 2: Prototype with microphone array at centre of a pair of eyeglasses and peripheral LEDs connected to an Arduino.

3. EVALUATION

To assess VisAural, we recruited nine participants (avg. 39.6 years, six male) who self-reported some degree of hearing impairment. We recorded their sound localisation performance (error rates and response times) both with and without VisAural and gathered their subjective impressions through loosely-structured interviews once the evaluation was completed. The study was composed of two parts. The first was to assess the hearing ability of each participant through an online audiometry tone test (ATT)[7], in which the participant's ability to hear different frequencies between 250Hz and 8kHz at different volume levels was measured. Any participant with any responses above 40 dBHL (indicating at least mild hearing loss) was included in the study. Any participant who did not meet this condition continued in the study but their data was not included in the analysis.

The second part of the study was a sound localisation task. Participants sat, surrounded by 6 evenly-spaced speakers in a semi-circular arrangement. Each participant had to localise 54 sounds. Each sound had three components: frequency (low, medium, high), volume level (low, medium, high) and a speaker number (1-6). The order of the sounds were randomised at the beginning of the study. The participant began the task by pressing the spacebar key, after which the first sound would play. The participant was instructed to press a number on a keypad relating to the speaker which they believed the sound originated from. After the participant had pressed the keypad there was a brief delay after which the next sound would play. This would repeat until all sounds had been played. This task was completed once with no assistance and once whilst wearing the prototype, and was counterbalanced between participants.

4. RESULTS & DISCUSSION

Through analysis of the evaluation data, no quantitative difference between participants' performance with or without the use of our prototype was found (see Figure 3). The response time for VisAural (5.8s) was significantly slower than the response time with no device (3.3s; paired t-test, $p<0.01$) (see Figure 4).

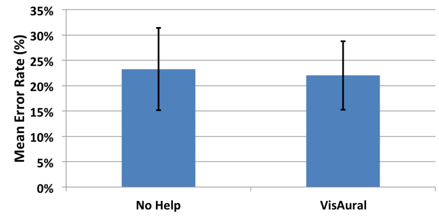

Figure 3: Mean error rates with and without assistance (± s.e.).

During follow up questions, we first found that participants were very enthusiastic about using their visual system to aid the task of sound localisation, with one participant noting that use of the system, "could become second nature". Second we found that the system needs to be faster at notifying the user of sound direction. This could be caused due to processing of the microphone array input. This delay may affect completion time (see Figure 4) and could affect error rates as one participant stated that the "Ambiguity [caused by the delay] overruled the device". Third, in order for both LEDs to light at once, indicating that the sound is directly in front of the user, the sound source needs a direct line of sight to the device. This turned out to be a key interaction element for participants but with one reporting that it was "Difficult to get both lights to appear", we determine that this field of notification needs improved. As a result of these findings, we are now working to reduce the response time of the prototype, as well as exploring the potential of more expressive visual cues.

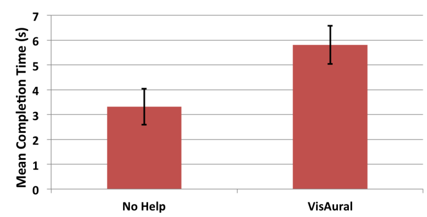

Figure 4: Mean completion time with and without assistance (± s.e.).

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