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Binaural Simulation of Echolocation in Pure Data

"Echolocation and Access for All" is a research project in Statsbygg (Norwegian Directorate of Public Construction and Property), in collaboration with Anders Buen (Brekke Strand Acoustics, Oslo), Jens Jørgen Dammed (Rikshospitalet/Oslo Univ. Hospital) and Edvart Sæter (Statsped Øst, Department of Visual Impairment, Huseby, Oslo). This project included recordings of clicks for echolocation in an anechoic room, and practical tests for finding objects and surfaces. Some results are published in Psychomusicology: Music, Mind, and Brain © 2015 American Psychological Association. 2015, Vol. 25, No. 3, 256–271 0275-3987/15/$12.00 http://dx.doi.org/10.1037/pmu0000077 (special edition in hour of Leo Beranek 100 years).

Simplified binaural simulations

Live real time auralisation of sending an oral click and receiving a reflection from a simulated surface at a given distance, using microphone and real time convolution techniques would have been highly interesting, but too problematic, as an undetermined delay of even a few milliseconds would jeopardize the details of the comb filtering and detection of echo limits. Instead we played back "dry" clicks recorded in the anechoic chamber through a Pure Data (Pd) patch, using binaural filters derived from Gardner and Martin's measurements of the KEMAR dummy head microphone at the MIT Media Lab [16]. In the patch, it was compensated for the 3.5 ms latency of the <*binaural~*> object in Pd.

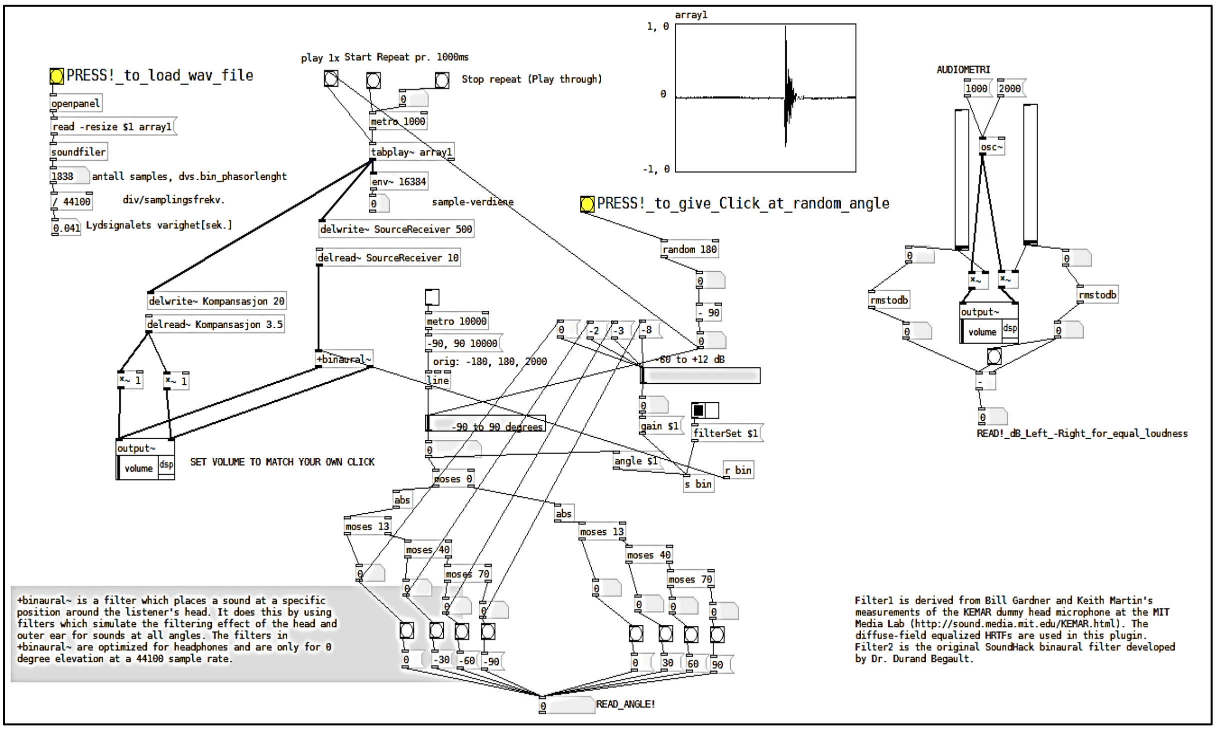

Fig. 1. Pure Data (Pd) patch

The tests were performed with different delays for the reflection, but only the results for 10 ms is shown here. In the Pad-patch it is possible to compensate for the directivity of the mouth by setting different (negative) gain.

The listeners used their own preferred headphones and the Pd patch included a rough hearing test comparing perceived Left/Right for 1 dB steps at 2 kHz. The level of the reflection relative to the direct sound was calculated by common free-field attenuation for the distance, adding an assumed, very small absorption factor (app. 0.05) for the surface at the actual mid-/high frequency band. The calculated total attenuation of the reflection compared to the direct sound was checked with the measurements in the anechoic room.

The listeners started the playback of the recorded click himself, but did not know the settings of the direction of the simulated reflection. The azimuth angle of the reflection was picked between -90^{o} (Left) and 90^{o} (Right) by a random generator. 5 test persons with normal hearing (male, non-echolocators) reported the perceived angle. Two additional persons found the task too difficult because they felt the sounds were so short, and did not participate.

Fig. 24 shows the binaural simulation of a “dry” click (recorded in empty anechoic room), and Pd-simulation of adding a single 10 ms reflection for angle=90^{o} (to the right of the clicker). In order to see the inter-aural time delay etc., this figure is for a relatively high gain of the reflection. We see that the reflection to the left ear is delayed 0.7 ms in excess to the right channel, corresponding to the extra travelling path around the head, and of course reduced in level due to the simulated effect of the head etc. as “screen”.

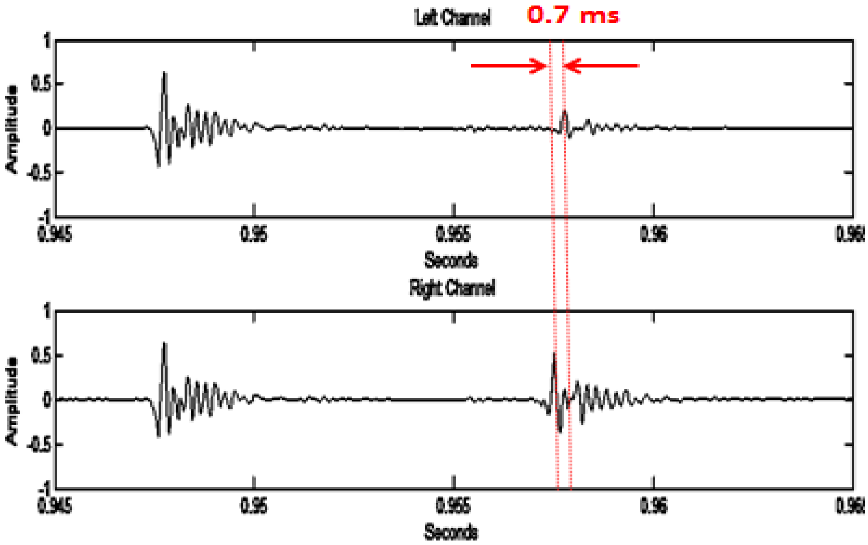

Fig. 2. Waveform of a recorded click with binaural simulation of a reflection from the right side of the (simuated) head.

Fig. 3 shows the frequency analysis (linear frequency). Black is Left and Red/dotted is Right. We clearly see that the comb filtering with CBTB of 100 Hz is larger on the right ear, towards the position of the simulated reflective surface.

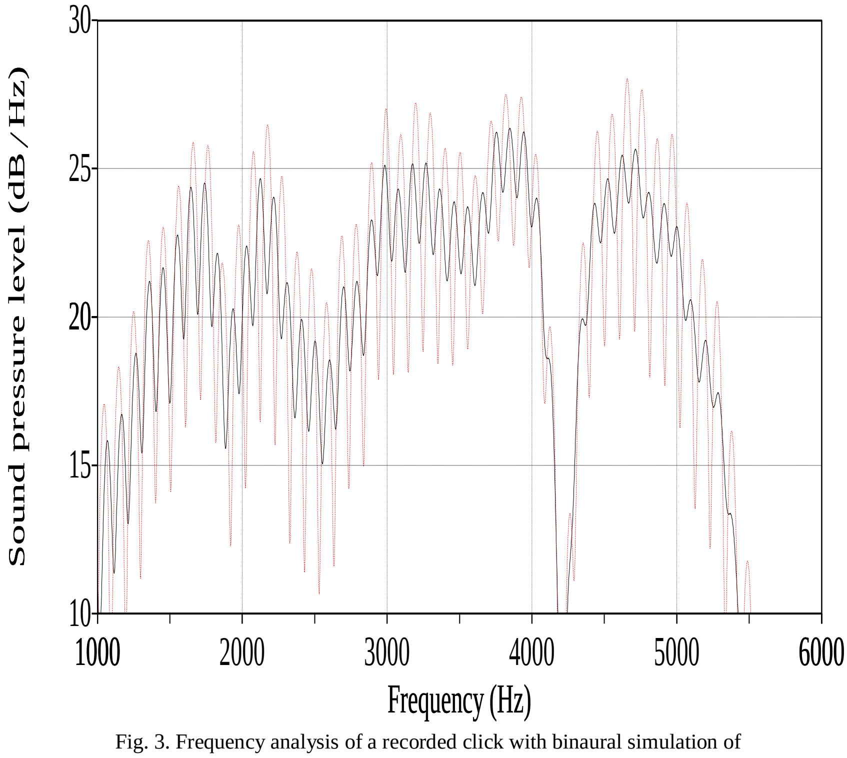

Fig. 3. Frequency analysis of a recorded click with binaural simulation of a reflection from the right side. Black= Left ear. Red/dotted=Right ear.

Overall results are given in fig. 4. for the test signals recorded “in-ear” in anechoic room for a 10 ms reflection. The vertical axes shows the azimuth angle as reported from the test person (right ear upwards), and the horizontal axes shown the “real” azimuth angle, as chosen from the random generator. A complete match should then give a straight 45^{o} line. The results are given for three settings of the gain of the reflection relative to the direct sound: 0 dB (reflection as strong as the direct sound recorded mono in the clicker´s ears), -8 dB, -12 dB and -18 dB. The last settings of the gain was to include a wider range, incorporating situations like if the reflecting surface material gave some absorption for 1-3 kHz, and reduced level due to the possible extra directivity of the mouth.

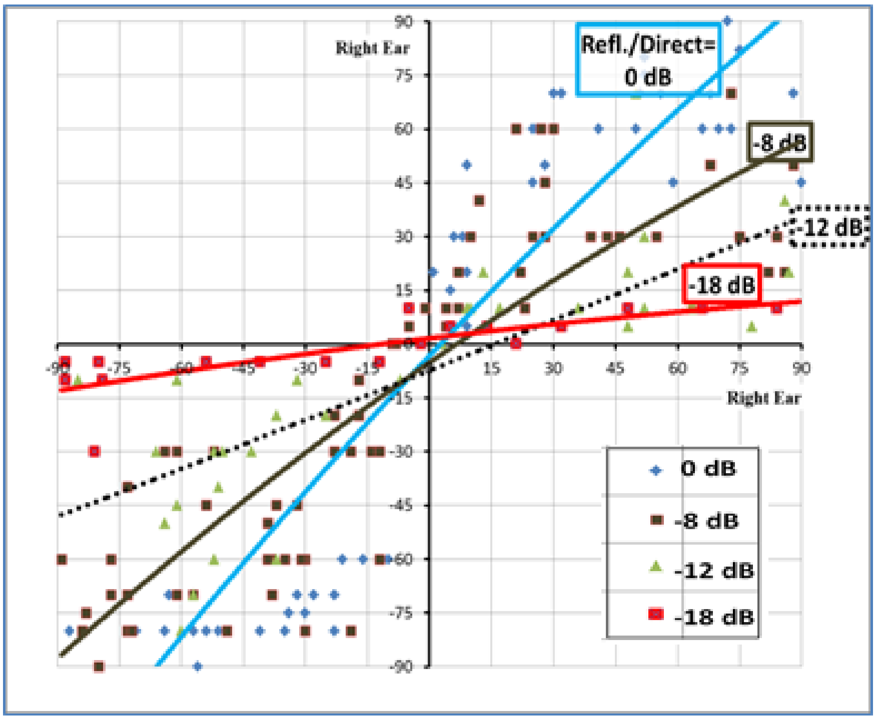

Fig. 4 Result of Blindfold test of binaural simulation.
Reflection with 10 ms delay.
Horisontal:Actual angle Vertical: Perceived angle.
Blue: Reflection Gain=0 dB
Brown: Reflection Gain=-8 dB
Black/dotted: Gain= -12 dB
Red: Reflection Gain=-18 dB
Clikc from 2 professionals. 176 test clicks

From fig. 4 we see that the *Left/Right* judgment is correct for nearly all measurements. The perceived angle is of course not always correct, but the trend line for Gain = 0 dB show reasonably good agreement. The ability of perceiving the "correct" direction of course decreases when the intensity of the reflection decreases: for G = -8 dB, the agreement is somewhat reduced. For Gain = -12 dB the ability of detecting "correct" angle is worse, and a position 90^o to the side was not perceived as such, but as a smaller angle. For Gain = -18 dB most of the measurements were perceived as "almost in the middle".

From the practical tests we saw a tendency of moderate estimates for the directivity of the mouth when clicking. If we include actual measured directivity for clicks, the gain should be gradually more decreasing as the angles increase. As an example we might use the values for 0 to -8 dB for the first ± 45^o, then the values for Gain = -12 dB for ± 45-60^o, and the values for Gain = -18 dB for angles more than ± 60^o. This could be smoothed to something like fig. 27, so this figure shows how directivity would be perceived when an echolocator listens to reflections of clicks from his own mouth reflected from a surface at different angles.

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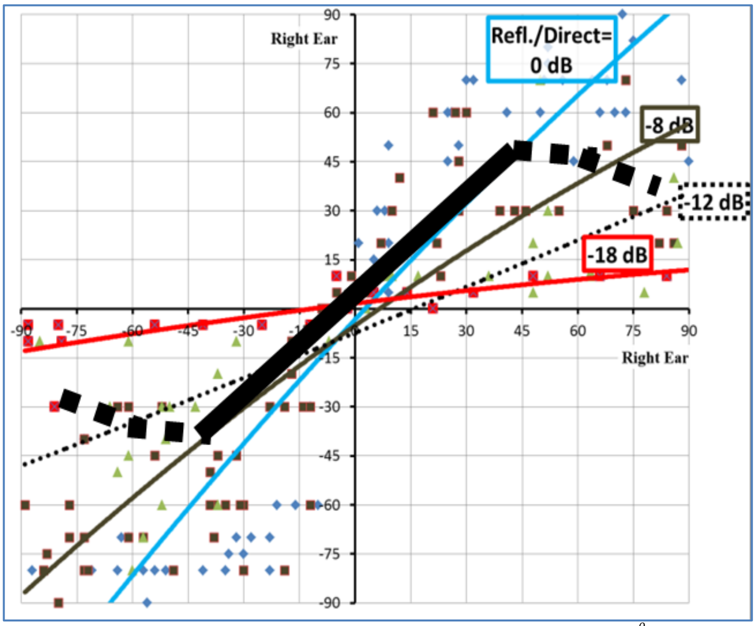

Fig. 5. Suggested curve for detectability of reflectons from surfaces at different angles (0^0=surfaces in front of head)

The simulations indicates that the hypothesis form the practical tests regarding the difflculty of deciding correct angle for angles over some 60^0, might be correct.

MEASUREMENT OF THE DIRECTIVITY OF THE EAR

The Pd/binural patch eas used to measure the directivity of the ear (Kemar Artificial Head), in the horisontal plane. The result is given in the following figure:

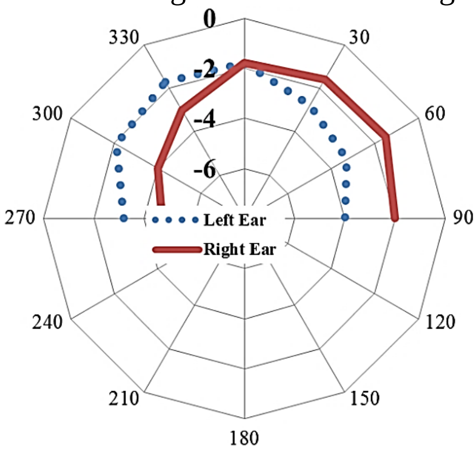

Fig. 6 Directivity of the ear(s) measured from the Pd/binaural patch

CONCLUSION:

High angles (reflecting surfaces close to 90^0 to the side) are hard to detect, and will probably be detected to appear from a smaller angle (if detected at all, due to lower level).

"Med klangfull hilsen!"

Tor Halmrast