First results of an experimental tactile hearing aid

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FIRST RESULTS OF AN EXPERIMENTAL TACTILE HEARING AID.

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ABSTRACT

The only practical way for deaf people to communicate with most hearing people in an everyday situation is using speechreading. However with speechreading alone it is not possible to recognize everything that is said. Further one cannot obtain any information about sounds that originate from sources that are not visible or give no visible information.
At this moment there are two possible ways to offer acoustic information artificially to profoundly deaf people. One alternative is the cochlear implant, which can only be used in a limited number of cases. The other is offering information to the tactile sense, by a so-called tactile hearing aid.
At Eindhoven University of Technology, an experimental vibro- tactile hearing aid has been developed. Since little is known about which information can be offered best in what way, the experimental aid will be used to investigate this. First experiments with both deaf and hearing subjects, offering formant and amplitude information at the same time, show a clear increase in speech reading recognition scores after a relatively short period of a couple of hours of training.

Key words: Communication aid, Deaf, Vibro-tactile

INTRODUCTION

Speech is used for the major part of everyday communication. However, when ones hearing abilities are less than average, it can be quite difficult to understand speech. Acoustic (or conventional) hearing aids are available for people with a light to moderate hearing loss (up to about 70 to 90dB loss) [1]. For people with a severe or complete hearing loss, these hearing aids are not sufficient for understanding speech. When the hearing loss is too high (but not complete), the conventional hearing aid can only help to supplement speechreading. Once this aid does not help any more, one has to fall back on other communication aids (or perhaps other means of communications, such as sign language [2]). People who are very good in speechreading might not have much benefit from these aids for understanding speech, yet for knowing that there is some sort of sound, and for a better control of their own voice, these aids can still be useful. Although we have no intention to label people, for simplicity reason we shall call this group of people, who can have no benefit of conventional hearing aids, profoundly deaf.

At this moment two types of communication aids are available for the profoundly deaf, that can offer information about sounds and supplement speechreading (or enable deaf people to understand speech without the need of speechreading). These aids are the cochlear implants and the tactile aids (or tactile hearing aids) [3]. The cochlear implants stimulate the acoustic nerve. For this reason they can be used only when the impairment is situated distal to the acoustic nerve (i.e. in the ear or the cochlea). Tactile aids stimulate the skin to transfer the acoustic information, and can be used, no matter where the impairment is situated. The only requirement for the use of a tactile aid is a proper functioning tactile sense.

However, tactile aids do have a drawback. The amount of information that can be transmitted through the skin is very limited. Literature [4,5] mentions transfer rates of about 30 bits per second, while speech, when optimally compressed, contains about 50 bits per second. This means that one cannot offer the skin all the information that is available in normal speech. One has to extract only a small part from the speech and offer that to the skin in an optimal way. It will be clear that the tactually offered information can merely be a supplement to speechreading. Also it can give nothing more than some clues (such as amplitude and basic frequency, or a limited representation of the frequency spectrum) about other –non- speech– sounds.

SPEECHREADING AIDS

We have focused on a communication aid for the profoundly deaf –other than a cochlear implant– for supporting speechreading. The available aids were not considered optimal, for various reasons. It appeared that most aids were used only for a short period. Also the rise in speechreading ability was not considered optimal. Finally we could not find any reliable comparison between the various tactile aids, as to which information can be offered best in what way and where.

Searching for alternative channels for offering speech information, we have found two possible solutions [6]. One is the tactile sense (as already mentioned), while the other is the visual sense. There have been some experiments to offer the information about speech (or sound in general) visually [3]. As far as we could find, these experiments were limited to laboratory situations [7]. We also believe that speechreading asks for so much concentration of the visual sense, that perceiving extra visual information will be very difficult (unless relatively large patterns are presented; one could compare this with sign language, where the listener usually focuses on the face of the speaker, whereas the signs can be made with virtually every part of the body, i.e. outside the focal area of the eyes of the listener [2]). Also the presentation of the visual information is still not solved satisfactory. Therefore we have concentrated on the tactile channel.

The available tactile hearing aids basically offer three different types of information [1]:

- The (band-pass filtered and) amplified sound signal.
- Pitch, usually combined with amplitude.
- Frequency (or spectral) information.

The information can be presented either by means of a vibro-tactile or an electro-tactile display. The displays that are used depend on the offered information [1,5,8]. When the speech signal is offered without much modifications (the first type of information), it is usually a single channel vibrator that is used [9]. Pitch and amplitude are often displayed on 2 channels: one channel presents the pitch, coded as a frequency, while the other channel presents the amplitude, coded as a sine wave with varying amplitude. Frequency information is displayed on a multiple-channel display, where the energy for each frequency band is displayed either as stimulation amplitude [10], or as place information on a two-dimensional display [5,11].

AN EXPERIMENTAL TACTILE HEARING AID

When our research started for a better tactile hearing aid, we tried to find which part from the speech (or sound) signal could be offered best in what way. Literature did not give an answer to this question. Only methods that have been used could be found, but no proper comparison between them (except for the comparison between e.g. two or three display methods for displaying one type of information). For this reason we decided to develop a system that is able to extract various sorts of information from a sound signal. We also wanted to be able to test the device in conditions other than laboratory conditions (i.e. in the field). This puts some restrictions about size, weight and energy consumption even on the very first prototype. It will be obvious that a final system simply must be small, light and battery operated, while it can work on the same set of batteries for at least some ten hours (without recharging the batteries).

The above mentioned requirements and restrictions were now and then quite contradictory. To design a system that is able to extract various types of information in real-time, with hardly any hardware modifications, meant that we had to use some sort of microprocessor. Signal processing is rather computing intensive work, so this processor has to run fast. However a processor that runs fast uses much energy. So, we had to find a processor that processes signals fast, yet uses little energy. We believe we have managed this reasonably well with the use of a Digital Signal Processor (DSP) from Analog Devices, the ADSP-2100 (KG) [12,13].

The system that we have used to obtain our first results is still only used in a laboratory condition [13]. Although the system already contains all features for portability (or better: wearability), it is assembled without special attention to this point. This is mainly done, because we wanted to be able to do measurements and modifications easily, should these prove to be necessary. In a system where all components are packed tightly together this will prove to be much more difficult.

For this system four types of signal processing and display algorithms have been written:

- Spectrum display
- Pitch + amplitude display
- Pitch + amplitude + small spectrum display
- Two formants + amplitude display

The second and the fourth method from this list were proposed as possible methods in a study with hearing subjects [14]. Until now only the last algorithm has been tried in an experiment with six subjects. The formant analysis algorithm is based on the Robust Formant Analysis technique [15]. Five formants are extracted (in real- time) from the speech signal, which is sampled at 10 kHz. The first and the second formant are displayed, together with the energy of the speech signal.

To display the extracted information we have used an Optacon (a small device from Telesensory Systems Inc. that enables blind people to read normally printed text; it displays the shape of the characters –or any dark/light pattern under the small camera– on the tip of a finger, by a 6 times 24 array of vibrating rods) [16]. The Optacon is slightly modified: its camera has been removed and the array can be fully controlled by the DSP in the tactile aid.

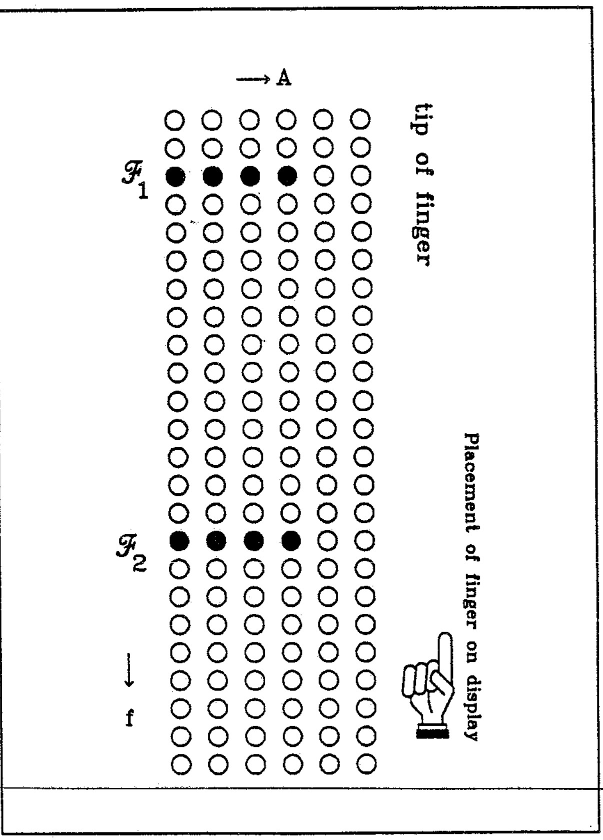

Fig. 1. Display method for two formants and energy.
Filled circles indicate vibrating rods, open circles: not vibrating

The formant information is displayed as two bars (see Fig. 1). The length of the bars indicate the total energy contents of the signal, while the place of the two bars (along the length of the display) indicate the frequency of the two formants. The information on the display is updated every 25 ms. The amplitude of the vibrating rods can be manually controlled by the user.

TABLE 1 Deaf Subjects.

	Sex / Age	Hearing remains	Notes
Subject D1 :	Female 28	appr. -100dB, Hearing aid	Formerly hard of hearing
Subject D2 :	Male 25	appr. -90dB, No hearing aid	Formerly normal hearing. Mountaineer.
Subject D3 :	Male 46	appr. -100dB, Hearing aid	Formerly hard of hearing

TABLE 2 Hearing Subjects.

	Sex	Age	Notes
Subject H1 :	Male	27	With experience on tactile perception and some on speechreading
Subject H2 :	Male	23	No prior experience on tactile perception
Subject H3:	Male	23	No prior experience on tactile perception

THE EXPERIMENTS

In order to validate the functioning of the experimental tactile hearing aid and to obtain some knowledge and feeling about the use and training of the aid, we have performed an experiment with a limited number of subjects. Since we believed that true reliable results can only be obtained when possible users of the device are used as subjects, we have chosen to use three deaf subjects. In addition to them we have also used three hearing subjects. Table 1 and 2 show some of the most important characteristics of the deaf and the hearing subjects.

To facilitate communication with the subjects, we have chosen to use post- lingual deaf persons. Their quality of speech [17] is usually better than that from pre-lingual deaf. Also their mastery of the (Dutch) language is usually better, which makes suggestions from them or the explanation of what is expected of them much easier.

Method

To validate the working principle of the tactile aid we have measured whether or not the speechreading recognition scores increased when the tactile supplemental information was offered. To perform this measurement we have used a number of short meaningful Dutch sentences, as compiled by Plomp et.al. [14,18]. Before we could start these measurements, it was necessary to train the subjects in perceiving artificial tactile information. This tactile training started with the recognition of patterns that were not related to any sound. The shapes of 10 different characters (A, C, H, I, L, O, P, S, U and X) [19] were presented, while the subjects should try to perceive these characters correctly.

Once the subject could recognize the characters sufficiently well, speech related information was presented. For this type of training the same kind of sentences as used for the measurements (but of course with different contents) were presented on a video monitor, where a speech therapist could be seen who spoke one sentence at a time. The loudspeaker of the video monitor was switched off, while the speech signal was used as input for the tactile aid. Hearing subjects were artificially deafened by presenting noise via a headphone. Each sentence was shown to the subject, while the extracted information was presented on the tip of a finger. The subject should try to repeat the given sentence as good as possible. When the repeated sentence was not correct, the sentence would be shown again, to offer the subject a second chance. When the sentence was not recognized, it was told or shown to the subject. Once the subject knew the sentence (either by seeing it correctly, or by being told), it was shown again. This training lasted for about 5 to 10 hours (net time, spread out over 8 to 12 days), depending on the speed with which the subject could get used to the tactile supplement.

After about one hour of training the first measurement was done. Both the speechreading recognition score without tactile supplement ($\mathcal{R}_s$) and with tactile supplement ($\mathcal{R}_{st}$) were obtained. After 5 to 10 hours of training this measurement was repeated. Finally the recognition score of the presented artificial patterns ($\mathcal{R}_c$) was taken. The recognition scores of the speech reading tests were determined by counting the number of correctly perceived phonemes, from thirteen presented sentences (about 300 phonemes). The recognition scores of the character were determined by presenting 30 characters in a random way (where each character was used precisely three times), while the number of correctly recognized characters was counted.

Results

The results from the experiments can be seen in table 3. Table 4 shows the statistical analysis of the results, obtained with SPSS-X [20]. The rise in recognition score ($\mathcal{R}_d$) is the relative rise: $[(\mathcal{R}_{st} - \mathcal{R}_s) / \mathcal{R}_s] * 100\%$. Due to the limited number of subjects, the standard deviation (and the 95% confidence interval) is relatively large. Yet even with this small number of subjects, one can conclude that there is a significant rise in the recognition scores, when tactile supplemental information is offered to the speechreading information. The hearing subjects show a less clear rise. The confidence interval for them is too large to say that the rise in recognition score is really significant. Since all three hearing subjects show a (slight) rise in recognition score during the second measurement, there is a good chance that

TABLE 3 Results of the Experiment.

	First measurement		Second measurement		Char.
	$\mathcal{R}_s$	$\mathcal{R}_{st}$	$\mathcal{R}_s$	$\mathcal{R}_{st}$	$\mathcal{R}_c$
Subject D1	77%	80%	69%	92%	73%
Subject D2	15%	24%	19%	31%	57%
Subject D3	74%	86%	51%	82%	80%
Subject H1	58%	59%	47%	49%	100%
Subject H2	48%	45%	44%	60%	83%
Subject H3	37%	36%	48%	53%	100%

TABLE 4. Statistical Evaluation of the Experiment.

	Mean value	Stand. dev.	95% confidence interval for mean	
$\mathcal{R}_s{}^1$	51.5%	23.5%	26.9%	76.1%
$\mathcal{R}_{st}{}^1$	55.0%	24.6%	29.2%	80.8%
$\mathcal{R}_d{}^1$ (D1..3)	26.7%	29.5%	-46.6%	99.9%
$\mathcal{R}_d{}^1$ (H1..3)	-2.3%	4.0%	-12.4%	7.7%
$\mathcal{R}_d{}^1$ (total)	12.2%	24.6%	-13.7%	38.0%
$\mathcal{R}_s{}^2$	46.3%	16.1%	29.5%	63.2%
$\mathcal{R}_{st}{}^2$	61.2%	22.4%	37.7%	84.7%
$\mathcal{R}_d{}^2$ (D1..3)	52.3%	16.7%	10.7%	94.0%
$\mathcal{R}_d{}^2$ (H1..3)	16.7%	17.0%	-25.6%	58.9%
$\mathcal{R}_d{}^2$ (total)	34.5%	24.7%	8.6%	60.4%
$\mathcal{R}_c$ (D1..3)	70.0%	11.8%	40.7%	99.3%
$\mathcal{R}_c$ (H1..3)	94.3%	9.8%	70.0%	118.7%
$\mathcal{R}_c$ (total)	82.2%	16.5%	64.9%	99.5%

Notes:

1 : Results from experiment 1
2 : Results from experiment 2

the confidence interval will be fully positive when more subjects will be used.

One can see from table 3 and 4 that some form of training is necessary to have some benefit from the device. Although the deaf subjects already show a slight rise in recognition score, the rise is only significant after sufficient training. The hearing subjects seem to have a slight decrease in recognition score when tactile information is offered, after virtually no training. The rise after more training is still behind that of the deaf subjects (in fact, statistically it could even be a decrease). This is probably due to the fact that the hearing subjects have only little or no experience with speechreading, while the deaf subjects have much more experience (even though the recognition score of one deaf subject is below the scores from the hearing subjects). When the hearing subjects get some extra information during speechreading, there is a fair chance that this will distract them from the speechreading. Only when the hearing subjects have obtained some speechreading experience, they are able to use some of the tactually offered information.

The scores obtained from the presented characters ($\mathcal{R}_c$) appear to have little or no correlation with the observed rises in recognition score ($\mathcal{R}_d$). Although presenting this kind of information can help to train the tactile sense, one should not derive the possible ability to use tactile supplemental information from the ability to recognize the presented characters.

CONCLUSIONS

From the experiments it appeared that offering supplemental information about speech by means of a tactile hearing aid can increase the speechreading ability. The method to present formant and amplitude information on the skin appears to work well. Also the developed experimental tactile hearing aid worked properly during the experiments.

The rise in speechreading ability can be observed especially well when deaf subjects are used. Whether deaf subjects should be used for comparing and evaluating a number of speech processing algorithms and display methods is not sure. A problem that might occur is that the deaf subjects get used too much to a system that can only be used temporarily. Also the deaf subjects might get used to a display or processing method that is not optimal. Changing either of the methods can be a great handicap for the subject.

During the experiments it appeared that the deaf subjects were very enthusiastic about the research. Further research about offering information about sound and speech in a proper way to deaf people seems to be a must.

REFERENCES

[1] D. Franklin - Tactile Aids: What Are They? - The Hearing Journal - 1988 - Vol. 41, No. 5. - pp. 18-25.
[2] Oliver Sacks - Seeing Voices - ISBN 0-330-31744-X - Picador / Pan Books - 1989 - 186 pages.
[3] J.M. Pickett - Sensory Aids - Gallaudet Encyclopedia of Deaf People and Deafness, Ed. by J.V. VanCleve, ISBN 0-07-079229-1 - McGraw-Hill Book Company Inc. - 1987 - Vol. 3. - pp. 13-15.
[4] C.E. Sherrick & J.C. Craig - The Psychophysics of Touch - Tactual Perception: a Sourcebook, Ed. by W. Schiff

& E. Foulke, ISBN 0-521- 24095-6. - Cambridge University Press - 1982 - pp. 55-81.

[5] J.C. Craig & C.E. Sherrick - Dynamic Tactile Displays - Tactual Perception: a Sourcebook, Ed. by W. Schiff & E. Foulke, ISBN 0-521- 24095- 6. - Cambridge University Press - 1982 - pp. 209-233.

[6] J.M. Pickett (1982)- Hearing through sight and feeling - IEEE Spectrum - April 1982 - Vol. 18, no. 4 - pp. 37-41.

[7] S.G. Fletcher - Seeing speech in real time - IEEE Spectrum - April 1982 - Vol. 18, no. 4. - pp. 42-45.

[8] C.E. Sherrick - Basic and Applied Research on Tactile Aids for the Deaf People : Progress and Prospects - Journal of the Acoustical Society of America - May 1984 - Vol. 75, no. 5. - pp. 1325-1342.

[9] G. Plant & A. Risberg - The Transmission of Fundamental Frequency Variations via a Single Channel Vibrotactile Aid - Speech Transmission Laboratory. Quarterly Progress and Status Report - 1983 - Vol. 2/3 - pp. 61-84.

[10] H. Leysieffer - A Wearable Multi-channel Auditory Prosthesis with Vibrotactile Skin Stimulation - Audiologische Akustik / Audiological Acoustics - Nov/Dec 1986 - Vol. 25 no. 6 - pp. 230-251.

[11] D.W. Sparks, P.K. Kuhl, A.E. Edmonds, G.P. Gray - Investigating the MESA (Multipoint Electrotactile Speech Aid) : The Transmission of Segmental Features of Speech - Journal of the Acoustical Society of America - Jan. 1978 - Vol. 63, no. 1. - pp. 246-257.

[12] Analog Devices - ADSP-2100 User's Manual : Second Edition - Analog Devices - 1986

[13] R.W.M. Mathijssen & W.H. Leliveld - Proposed use of a Digital Signal Processor in an Experimental Tactile Hearing Aid for the Profoundly Deaf: Preliminary Communication - Journal of Medical Engineering & Technology - 1989 - Vol. 13, No. 1/2. - pp. 84-86.

[14] M. Breeuwer M. - Speechreading supplemented with auditory information - Ph.D. Thesis - ISBN 90- 6256-207-8 - VU Uitgeverij, Amsterdam - 1985 - 103 pages.

[15] L.F. Willems - Robust Formant Analysis for Speech Synthesis Applications - European Conference on Speech Technology. Edinburgh - Sept. 1987 - Vol. 1. - pp. 250-253.

[16] J.C. Bliss, M.H. Katcher, C.H. Rogers, R.P. Shepard - Optical- to-Tactile Image Conversion for the Blind - IEEE Transactions on Man- Machine Systems - 1970 - Vol. MMS-11, no. 1 - pp. 58-65.

[17] B. Maassen - Marking Word Boundaries to Improve the Intelligibility of the Speech of the Deaf - Journal of Speech and Hearing Research - 1986 - Vol. 29 - pp. 227-230.

[18] R. Plomp & A.M. Mimpen - Improving the reliability of testing the speech reception threshold for sentences - Audiology - 1979 - Vol. 18 - pp. 43-52.

[19] X. Wang - Preliminary Investigations on Tactile Perception of Graphical Patterns - Eindhoven University of Technology : Research Reports, EUT Report 90-E-239. ISBN 90-6144-239-7 - 1990 - 20 pages.

[20] SPSS - SPSS-X User's guide : 3rd ed. - SPSS, Chicago. ISBN 0- 918469-51-1 - 1988 - 1072 pages.