PROSPECTS FOR THE APPLICATION OF HIGH TECHNOLOGY TO HEARING AIDS*

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ABSTRACT

The rapid development of sophisticated consumer electronic products during the last decade has led to the expectation of a similar leap forward in the field of hearing aids. This paper discusses reasons why this has not occurred and indicates areas where one might reasonably expect to apply high technology to hearing aids in the future.

SOMMAIRE

Les progrès rapides enregistrés au cours des dix dernières années dans la mise au point d'appareils électroniques sophistiqués ont permis d'espérer les mêmes résultats dans le développement d'appareils de prothèse auditive. Cette communication explique pourquoi ces espoirs ne so sont pas concrétisés et discute des domaines dans le développement d'appareils de prothèse auditive plus perfectionnés où la haute technologie devrait normalement jouer un rôle dans les années à venir.

The advent of the digital wristwatch and the pocket computer has led to the inevitable comparison of the technical sophistication of the modern hearing aid with these popular electronic devices. The hearing aid is invariably the loser in such a comparison, and many people, both laymen and professionals, are asking why this should be the case. There are many reasons, not only technical, but financial, medical, psychological and sociological, as well. This paper will attempt to discuss some of these, to present an overview of recent attempts to improve the technical sophistication of hearing aids and to indicate areas where one might reasonably expect to apply high technology to hearing aids in the future.

THE TECHNOLOGY GAP

To an observer outside the hearing aid industry, the hearing aid of 1982 bears a striking resemblance to the hearing aid of 1972 or, in some cases, the hearing aid of 1962. This is not to say that there has not been progress. There has been a revolution in transducers, with electret microphones now used exclusively and receivers reaching new levels of miniaturization. Integrated circuits now are used in the vast majority of hearing aids, and many manufacturers are converting to thick or thin film hybrid circuits from printed circuit board construction. Still, the modern hearing aid remains little more than a miniature, personal PA system. To be sure, this PA system frequently has some form of frequency shaping and automatic gain

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control (AGC), but these features were found in the vacuum tube aids of the 1940's and 50's. Where are the microprocessors, the 64 K memories and the digital readouts? Why no built-in snooze alarm? In answer, one should first examine the needs.

THE AMPLIFICATION NEEDS OF THE HEARING IMPAIRED

In June of 1981 a conference was held at Vanderbilt University to address the problem of defining research needs in the area of amplification for the hearing handicapped. Prominent researchers from around the world were invited to present and discuss papers on selected topics. The proceedings of this conference, now published,[23] give no definitive indication of the amplification needs of the hearing impaired. There was, however, a general consensus that much more research needed to be conducted. This is a major reason for the lack of progress in the development of sophisticated hearing aids.

Research into hearing impairment is as old as the field of acoustics itself, yet, since World War II, little progress has been made. In fact, "thousands and thousands of hours of research in the behavioral field ... was misguided because of misunderstanding of the limitations of the physical measurements."[13] Because hearing aid research has been viewed as trivial and uninteresting by acousticians, much of the research burden has fallen to those lacking the multidisciplined training required to make such exacting work meaningful. As a consequence, hearing aid engineers, blessed with a technological smorgasbord, are constrained to a diet of bread and water by a lack of valid specification of the need.

The situation is further aggravated by a lack of meaningful criteria upon which to judge success or failure. For decades, speech discrimination has been sanctified as the ultimate measure of goodness for a hearing prosthesis. It is such a logical concept that it has been embraced by the research lab, clinic and hearing aid dispenser alike. And yet, things psychological are not always logical, and the speech discrimination test is no exception. In the first place, the test/retest reliability for tests of manageable duration is such that they are capable of differentiating only gross differences in amplification systems.[25] Secondly, different test materials have different sensitivity to various electroacoustic parameters.[11] Thirdly, substantial differences in measured intelligibility may be insignificant in the presence of contextual and non-verbal cues. Fourthly, there are other dimensions of equal or greater importance. Killion[12] has emphasised the importance of sound quality to the user. It often has been shown that, left to their own devices, individuals usually will not choose a hearing aid that optimizes their speech discrimination.[12] A hearing aid that is not used is of no benefit, regardless of the speech discrimination score. The same can be said for a hearing aid that is not purchased. The point is that speech intelligibility is only one measure of a multi-dimensional problem. It is the one that has received the most attention but, in fact, may not be the most important. It is essential to keep this in mind when evaluating potential technological improvements. The development of quantitative measurement methods for some of these other dimensions will be necessary if progress is to be made.

RECENT TECHNOLOGICAL SOPHISTICATION ATTEMPTS

Over the past decade, new technology has been incorporated into hearing aids in a variety of ways. A brief review of the results of this activity will give an indication of the current state of the art.

PHYSICAL PACKAGING

Miniature electret microphones have allowed smaller hearing aids to be built. This is due not only to their reduced dimensions but also results from their significantly lower vibrational sensitivity which permits mounting in closer proximity to the receiver. Smaller receivers, monolithic integrated circuits and hybrid construction techniques all have contributed to size reduction. In-the-ear (ITE) hearing aids with good performance characteristics have been made possible and have captured nearly 40% of the U.S. market in the past eight years. The canal aid, smaller than the ITE, just now is appearing and undoubtedly will find a market niche as well. These miniature aids show some technical merit such as shifting the primary resonant peak to around 2.7 kHz and by providing improved high frequency performance due to the elimination of tubing. However, their main appeal is cosmetic. Professionals too often give this dimension a low priority, but consumers do not. A hearing aid must be purchased and worn to be of benefit.

GREATER ADJUSTMENT FLEXIBILITY

Integrated circuits, hybrid technology and miniaturized components have permitted the design of very flexible hearing aids. Current aids can have as many as six adjustable controls. Both audiologists and hearing aid specialists asked repeatedly for more fitting flexibility.[17] However, according to a recent report, 60 to 80% of aids returned for repair have untouched fitter adjustments.[19] While these adjustments add to the cost of the aid, there really is no way to verify the benefits of the alterations they may provide.

SMOOTHER WIDEBAND RESPONSE

Thanks largely to the work of Carlson[4] and Killion,[12] hearing aids with smooth response out to 6 kHz are available and being applied. Several researchers have shown that low frequency amplification does not degrade intelligibility if it is combined with increased high frequency response.[1,20,21] The resulting sound quality is much more acceptable to the user than that produced by the "it has to hurt to be good" high frequency emphasis aid.

AUTOMATIC GAIN CONTROL

Considering the reduced dynamic range of the patient with a sensorineural hearing loss, the use of some form of automatic gain control (AGC) seems so logical that it ought to be viewed cautiously. There have been few studies on the benefits of long-term automatic volume control (AVC),[15,22] and the results seem to indicate that, although discrimination is improved for varying input levels, users generally do not prefer such systems.

Short-term AGC (compression) has been studied extensively with few clear conclusions.[26] It does appear to offer some benefits when tested with varying input levels, but long-term AVC may be more effective.

Despite this lack of consensus, AGC has been used in hearing aids for many years.[26] The use of integrated circuit and hybrid technology has resulted in more sophisticated AGC aids that permit the user to set the average output sound level with the manual volume control and have it automatically maintained. In addition, operating transients and distortion have been reduced.

AUTOMATIC HIGH PASS FILTERING

It has long been known that background noise has a predominance of energy below 1500 Hz, while the important speech cues lie above 1500 Hz. Manual low-cut filters have been incorporated into hearing aids for years. Integrated and hybrid circuits make it possible to produce wearable hearing aids in which the low frequency gain is automatically reduced by a steady state low frequency signal. This permits wideband operation for good sound quality, but narrow band operation when required for noise reduction.

APPLYING HIGH TECHNOLOGY

The confusion that has resulted from the last three decades of hearing aid research has restricted the number of areas where one might apply advanced technology. If the ear is viewed as a communications channel having some fixed limiting level and a sensorineural hearing loss is considered to, among other things, raise the noise floor, then the task of the hearing aid can be better appreciated.[5] It must compress the incoming sound into a dynamic range which lies between the upper limit and the elevated noise floor. The capacity of the channel has clearly been reduced. It would, therefore, be advantageous if unnecessary or competing signals could be removed to allow the remaining channel capacity to be best utilized. Most of the recent advanced laboratory systems are aimed at achieving one, or both, of these goals.

MULTIBAND COMPRESSION

Multiband compression has received much attention since Villchur's earlier work.[24] By dividing the spectrum into two or more bands, it is possible to provide separate compression parameters for each, thereby permitting close compensation for the reduced dynamic range of the hearing-impaired ear. Villchur reported considerable benefits for subjects with severe sensorineural loss, under conditions of varying input levels. Others have produced negative results for moderate losses under constant input conditions, and, in general, there is not a consensus as to the benefit of multiband compression.[26] Villchur's original system employed analog techniques, while those of other researchers were partially digital. Current technology is capable of producing one or two channel analog devices. Questions have been raised as to what can be gained from a digital approach. Uncertainty as to the aceptance of such devices has prevented commercial development. Additionally, the fitting of such systems will severely tax the current distribution system. Successful commercialization of multiband compression hearing aids awaits unequivocal proof of benefits and the development of fitting techniques and equipment compatible with the realities of the distribution system.

LOOK-AHEAD COMPRESSION

Lood-ahead compression is a relatively new concept, designed to provide instantaneous dynamic range limiting without introducing objectionable distortion or altering the fine temporal structure of speech. Such a system delays the signal by a few milliseconds and adjusts the gain at the instant of zero crossing so that the signal peaks all reach the same level. Hendrickson[10] has produced recordings of speech processed in this manner, and the sound is quite normal. His tests with hearing-impaired listeners show a significant advantage, but more work is required.

The output waveform produced by this system is not unlike that reported in earlier work by Gregory and Drysdale.[9] Their system modulated a high frequency carrier, clipped the single side band suppressed carrier signal, filtered out the distortion products and demodulated the result. Their test results for words and sentences for a range of subjects showed a significant improvement. This system is easier to implement with analog techniques, using existing technology, than the look-ahead system. The look-ahead system, on the other hand, could be implemented in integrated circuit form without major technical problems. If substantial benefits can be reliably demonstrated and the high frequency carrier clipping technique is not found to be equivalent, then this is a good candidate for the application of high technology.

ACOUSTIC FEEDBACK SUPPRESSION

Acoustic feedback is a very common complaint from hearing aid users. It is caused by leakage from a poorly sealed earmold combined with high acoustic gain in the hearing aid. Preves[9] constructed a number of circuits using adaptive notch and phase shifting techniques which allowed a gain increase of about 10 dB before the onset of feedback. He states that his circuits could fit into headworn hearing aids and operate from a 1.3 volt battery.

ADAPTIVE NOISE REDUCTION

There has been much interest in adaptive noise reduction in recent years. This interest originated with the military as a result of the move to low bit rate digital communications links. The environment in which these digital encoders must operate is very noisy and low data rate encoders are very sensitive to noise since the process of data reduction removes redundancies necessary for robustness. This is very similar to the case of sensorineural hearing loss, where data reduction occurs as a result of damage to the digital encoder (cochlea).

The adaptive noise filter is a digital or analog filter having a response that is controlled to be the inverse of the noise spectrum at any instant. These filters generally improve the quality of the speech but not the intelligibility; this is dependent on the noise spectrum and level. In the hearing aid field, the work of Graupe and Causey[7,8] appears promising, but few details have been published. Doblinger[6] has published early details of a portable system constructed with commerical signal processing of integrated circuits. The performance appears to be superior to other systems.

Bandwidth	300 to 3300 kHz
Noise reduction	32 dB
Limit (white noise)	-5 dB S/N
Limit (1/f noise)	0 dB S/N
Circuit	5 Intel 2920
Power supply	+/- 5 V @ 75 mA
Chip size (each)	5 x 6 mm
Estimated parts cost (US $)	$400.00

The possibility of producing this system in a headworn instrument, at a reasonable price, is not good. The Intel 2920 has been available for about three years, and the price is not likely to decrease. The application of newer processing technologies could certainly reduce the supply voltage and current to tolerable levels, but a five-fold reduction in size also is required. This is highly unlikely, and the cost of such an attempt would run in the millions of dollars. Further, such a device would be expensive to produce due to limited volume and low yield.

There are, however, analog techniques that can approximate the digital system using available components and technology. For example, a multiband compressor with long attack and release times will act as an adaptive filter, reducing the gain in those channels having steady signals present. The automatic high pass filter previously mentioned is a special case of such a system.

There are other ways in which these adaptive systems may be simplified for headworn applications. The number of filters could be reduced, or the filters could be analog types with only the controlling function implemented digitally. Such simplifications cannot be critically evaluated without some valid means of measuring their worth to the user. It is probable that such systems will improve intelligibility in some situations. It is also possible that they will make listening easier, although in a real environment the sound of constantly altering frequency response as people move about is a sound effects man's delight. However, at some point, the value of these features must be weighted against the cost, and for the foreseeable future, the cost is high.

FEATURE ENHANCEMENT

Feature enhancement involves the use of a computer to alter the speech signal to make it more intelligible. Ono[16] recently reported on a system developed in Japan, which enhances speech in inserting pauses, and altering phoneme duration and amplitude. Initial discrimination tests appear promising, and there are plans to produce a wearable unit. The computational requirements for such a system are not as great as for an adaptive noise filter, but a headworn unit is unlikely in the near future.

PROGRAMMABLE HEARING AIDS

In 1975, Blackledge[2] reported test results for a wearable, programmable hearing aid. This aid is programmed in conjunction with a special sound field master hearing aid by making screwdriver adjustments until an indicator light comes on. More recently, it has been proposed[14] to install a programmable read only memory (PROM) in a hearing aid and program it from a special audiometer. The PROM then controls the hearing aid characteristics via digital to analog converters and analog gates.

Technically, this system can be realized with existing technology. It possibly can be done using a semi-custom CMOS circuit at moderate expense. Power consumption will not be a problem, but producing an analog/digital CMOS IC to work at 1 volt may be.

In this case, the real questions are not of a technical nature. Does it make sense to replace trimmers that are rarely adjusted with a complex memory and control IC and the equipment needed to program it, when there is no clear evidence that the adjustments produce any benefit?

CONCLUSIONS

There is unlikely to be any rapid application of high technology to hearing aids for a number of reasons. Few genuine needs can be positively identified, and those that can, generally require very sophisticated, special purpose integrated circuits. The hearing aid market is not large enough to warrant the large expenditures necessary to produce such components. Neither the space, nor the required power source for these signal processing circuits, is likely to be available in a headworn hearing aid. And finally, it is unlikely that the consumer will pay the additional $500 to $1000 that such hearing aids almost certainly will cost unless the benefits are dramatic. After all, fewer than 20% of hearing aid users in North America wear two hearing aids and yet binaural fitting is the most cost effective signal processor currently available.

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