8대역 비선형 라우드니스 교정 디지털 보청기

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A Digital Hearing Aid with 8-band Curvilinear Loudness Fitting

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ABSTRACT

In this paper, a body-worn type digital hearing aid (DHA) based on a dedicated DSP chip is developed. A fitting software running on a PC supported by the Win95 OS is also developed. The fitting protocol is based on the NAL-R procedure applied to eight frequency bands, but it is designed to support a curvilinear fitting to cope with the nonlinear perception of hearing-impaired listeners. Preliminary subjective tests regarding the speech intelligibility and perceived quality revealed that the new DHA could be of benefit to hearing aid users.

INTRODUCTION

For human being, 'hearing' is more than a mere sensory mechanism. With a loss of hearing, man is restricted from his or her normal social activity, which may in turn cause undesirable influence on mental health [1]. In order to compensate for this kind of handicap, many researches have been conducted [2, 3, 4]. The objective of the hearing aid is to modify the acoustic signals to produce the best possible match between the outputs of simulated normal and impaired ears. Various signal processing algorithms so far have been suggested to achieve this goal. Modern hearing aids can be subdivided into three groups: analog, digital, and analog/digital hybrid hearing aids. Though majority of currently available hearing aids are analog devices employing conventional analog circuits, the digital technology has offered new possibilities for noticeable advances of hearing aids. Using digital technologies, the *ad hoc* nature of conventional hearing aids can be replaced by a more rigorous procedure. Furthermore, those technologies has provided convenient tools for implementing powerful features in hearing aids, such as nonlinear amplification, noise reduction, and feedback cancellation [2]. Despite considerable possibility of the digital technology, issues on the size, computational capacity, and power consumption of the DSP chip have limited its use for hearing aids in comparison with the analog devices. Those issues have been main obstacles to the implementation of wearable digital hearing aids. As an effort to provide a feasible solution to those problems, we developed a dedicated digital signal processing (DSP) chip for hearing aids, called digital hearing aid processor (DHAP) [6]. The DHAP employed a 16-bit programmable DSP core being capable of performing 30 MIPS with 3V power supply. The developed DHAP is suitable to implement highly sophisticated DSP algorithms in small wearable units with low power. It compensates for wide range of hearing losses and allows a sufficient flexibility for the system upgrade as well as algorithm development.

This paper concerns a development of a digital hearing aid (DHA) that supports a curvilinear loudness correction in eight frequency bands. The DHA unit employs a DHAP for signal processing and it is powered by three AAA batteries. The DHA unit has dimensions of 7.5×5.5×1.5 cm, and its weight is 32g without batteries. It is also equiped with a battery charger unit.

EIGHT-BAND LOUDNESS CORRECTION ALGORITHM

Figure 1 shows a schematic diagram of the eight-band loudness correction algorithm [6] adopted in this study. Within the spectrum estimation procedure, the energy of input signal is estimated for each frequency band to compute a time-varying correction factor. It should be mentioned that hearing losses are generally measured using narrow band (pure tone) signals and the incoming sounds consist mainly of broadband signals. To account for the loudness perception of the input complex sounds, the acoustic energy, rather than the magnitude, is measured.

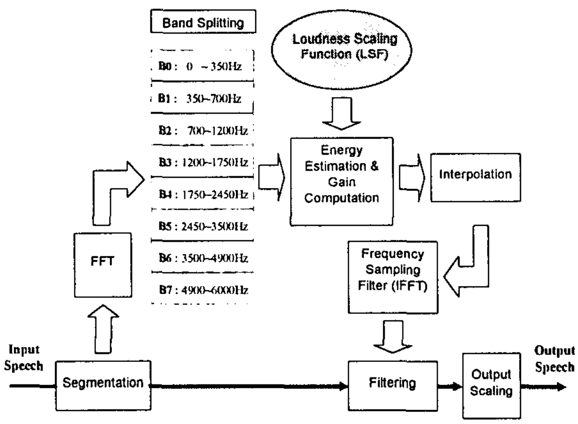

Figure 1: Block diagram of the eight-band loudness correction algorithm.

Sampled input signal is segmented into windowed blocks of 128 samples without overlap. Hamming window is applied to the input for the segmentation. Each block is then transformed into the frequency domain via FFT to obtain energy estimates in eight frequency bands. After computing the logarithm of the energy, a level adjustment of input energy is performed according to a predefined compression function [6]. Given information about the hearing loss of the patient, the gain for the momentary amplification or attenuation in decibels is computed using the loudness scaling function (LSF). To represent the nonlinear feature of the audiometric function, the LCF is broken into three equally spaced regions. Each region covers equal level range. Thus, different compression ratio, *i.e.*, slope of the curve, can be applied to the input according to the input level. In this way, complex compression schemes such as the curvilinear correction [7], or expansive characteristics for levels below the noise level to avoid an over amplification of background and quantization noise can be implemented. After obtaining gain factors for eight frequency bands, the acoustic amplification is accomplished in the time-domain by designing a finite impulse response (FIR) filter with which the input signal is modified into a desired form.

DHA PROCESSOR

The DHAP is based on a general purpose 16-bit DSP core (SSP1605) which performs maximum 33 MIPS at 33 MHz system clock with 3.3V power supply. The processor is composed of seven units: DSP core, 4 program ROM, data RAM, peripheral interface unit (EPIU), codec interface unit (CIU), serial electrically erasable PROM (EEPROM) memory interface unit (SEPMIU), and universal asynchronous receiver-transmitter (UART) interface unit (UIU). Figure 2 shows a schematic diagram of the DHAP. A real-time software implementing the curvilinear loudness correction in eight frequency bands required 100k clock cycles to process one frame (128 sample) data, which corresponds to 9.4 MIPS complexity. Sizes of the program ROM and data RAM are 4Kwords and 1Kwords each. To support an interface between the DSP and PC, the UART interface unit (UIU) is comprised in the processor. A asynchronous communi-

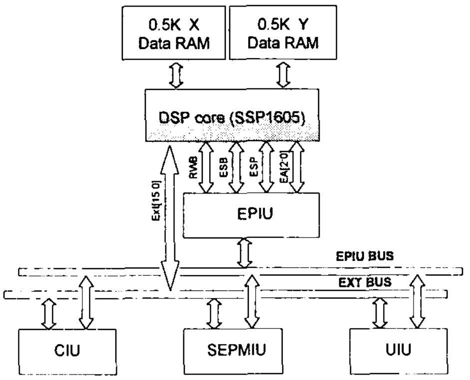

Figure 2: Schematic diagram of the DHAP.

cation protocol was chosen to minimize physical connections between the host PC and the DHAP. The fabricated DHAP has dimensions of 5,500×5,000 μm^2 that is small enough to fit for wearable hearing aids. Moreover, the chip features a low-power operation manageable with small batteries.

DIGITAL HEARING AID WITH EIGHT-BAND CURVILINEAR LOUDNESS FITTING

A body-worn type digital hearing aid was developed using a dedicated DSP chip (DHAP). Figure 3 shows a schematic diagram of the digital hearing aid, and Figure 4 shows the actual system. The hearing aid unit includes

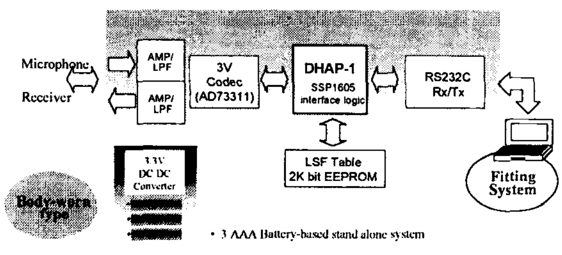

Figure 3: Block diagram of the prototype system based on the DHAP chip.

a DHA processor for signal processing, a 16-bit codec (AD73311) for data IO, and a 2kbit EEPROM for fitting data storage. It also includes microphone and a receiver in conjunction with corresponding analog circuits. Since the algorithm determines gain factors automatically according to the frequency and level of input, it doesn't require volume controls for adjusting output level. But for the purpose of input/output calibrations, the unit has two volume controls. 3.3V power is supplied with three AAA batteries together with a 3.3V dc-dc converter. The hearing aid unit has dimensions of 7.5×5.5×1.5 cm, and its weight is 32g without batteries. It also equipped with a battery charger unit as shown in Figure 4.

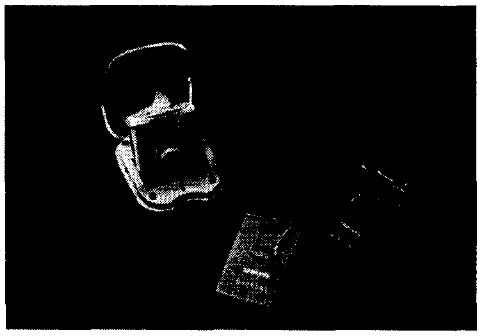

Figure 4: Samsung DHA units.

A fitting software running on a PC supported by the Win95 OS was also developed. The fitting protocol is based on the NAL-R procedure [5] which is one kind of threshold-based prescriptive fitting strategies. However, to accommodate fitting-by-loudness (FBL) strategies [7], the software enables one to adjust LSF curves on the PC screen according to the loudness growth of a particular person with impaired hearing. By applying hearing thresholds measured with pure tone signals to the fitting software, the user will see the LSF's that describe desired output levels for the particular subject with hearing impairment. On the screen the user can adjust the compression ratio for each segment of LSF curves. Once the LSF adjustment is done, resulting LSF tables are downloaded to the DHA set. Figure 5 shows windows presented by the fitting software.

Both the speech intelligibility and perceived quality have been evaluated with actual speech for subjects with hearing impairments. Four adults aged 28 to 42 served as subjects for the evaluation. The subjects' hearing

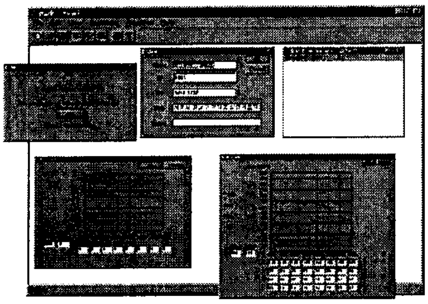

Figure 5: Fitting software windows.

thresholds (HT) and uncomfortable loudness level (UCL) were measured through conventional pure-tone audiometry. Later then, the DHA set adjusted by the fitting software. The subjects had moderate-to-severe sensorineural hearing impairment and all four were using analog-type hearing aid devices. The speech intelligibility was measured with 50 nonsense syllables, and the subjects were asked to compare the sound quality in terms of overall impression and softness with the new DHA and old devices of their own. Test results revealed that better speech intelligibility could be obtained with the new DHA for all subjects but one. However, the subject who didn't show improvement had no difficulty to understand normal speech without hearing aid regardless of 55dB HL in average. All four subjects judged the new DHA as the one that had much better sound quality.

CONCLUSIONS

A body-worn type digital hearing aid (DHA) was developed. The DHA unit employed a dedicated processor for signal processing and it was powered by three AAA batteries. A fitting software running on a PC with Win95 OS was also developed. The fitting protocol was based on the NAL-R procedure applied to eight frequency bands, but it also supports a curvilinear fitting to cope with the nonlinear perception of hearing-impaired listeners. Preliminary subjective tests regarding the speech intelligibility and perceived quality revealed that the new DHA could provide significant benefits to hearing aid users.

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