ARCHIVES OF ACOUSTICS
33, 4 (Supplement), 153–158 (2008)

HEARING AID FITTING METHOD BASED ON FUZZY LOGIC PROCESSING

Piotr SUCHOMSKI, Bożena KOSTEK, Andrzej CZYŻEWSKI

Gdańsk University of Technology
G. Narutowicza 11/12, 80-952 Gdańsk, Poland
e-mail: pietka@sound.eti.pg.gda.pl

Institute of Physiology and Pathology of Hearing
Zgrupowania AK Kampinos 1, 01-942 Warszawa, Poland

(*received June 15, 2008; accepted November 3, 2008*)

One of the most important steps in a hearing aids fitting procedure is determining hearing dynamic characteristics. The hearing dynamic characteristics are typically calculated on the basis of loudness scaling test results. The problem is that the loudness scaling test results are presented on a loudness category scale, but a hearing prosthesis requires numerical parameters to be fed. A fuzzy logic method is useful for processing parameters expressed in human natural language. In this paper a fuzzy logic-based system for loudness scaling result processing is shortly presented. On the basis of the developed fuzzy system a way to shorten the loudness scaling test was found out.

Keywords: hearing aid fitting, fuzzy logic systems, loudness scaling.

1. Introduction

Generally, a hearing aid fitting process can be described as scaling of wide-ranged dynamics of speech to the narrow-ranged dynamics of impaired hearing. To solve this problem, most of hearing aids use dynamic processors such as a compressor and expander [7].

To obtain a hearing dynamics (HD) characteristics, loudness scaling test (LST) results are needed. To asses loudness level natural language is used, but hearing aid fitting requires parameters on a numerical scale. Fuzzy logic is one of the simplest artificial intelligence methods, which is especially useful in converting parameters expressed in a natural language to proper parameters on a numerical scale [4]. Therefore, this paper is dedicated to the use of fuzzy logic to LST results processing. When developing the fuzzy logic system (FS) a way to shorten the LST was elaborated. Principles of this method are presented in the following paragraphs.

1.1. The loudness scaling test principles

In clinical practice several types of LST are used. For the method developed a well-known LGOB method (Loudness Growth in 1/2 Octave Bands) was chosen. The LGOB rules are simply and easy to implement. Moreover the LGOB principles are similar to other commonly used LST such as e.g the WHF (*Wurzburger Horfeld*) method, but the LGOB test principles are easier to understand [1, 5].

During the LGOB subjective loudness evaluation a patient is listening to test signals which loudness level is changed randomly. The patient has to assess loudness sensation for each test signal using the prescribed seven point loudness category scale (e.g. very quiet, quiet, comfortable, loud, very loud, uncomfortably loud). Test signals consist of the white noise signal filtered in four half octave bands with the middle frequencies: 500, 1000, 2000 and 4000 Hz. Each test signal is presented at least three times during the whole test. A patient's responses are collected for each test signal. When the test is finished, a loudness scaling characteristics is determined. The obtained curves (for each examined frequency band and for each examined ear) describe loudness scaling characteristics (Fig. 1).

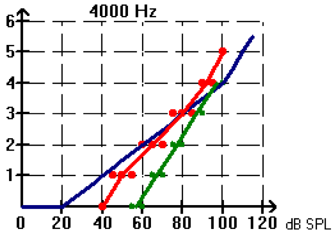


Fig. 1. Example of loudness scaling characteristics.

2. Employing fuzzy logic for Loudness scaling processing

The LST results are presented as a loudness category scale vs. the input loudness level, but a hearing aid amplifier requires characteristics in the form of the output loudness level as a function of the input one. It means that converting LST results from the loudness category scale to the numerical decibel scale, which represents output loudness level, is required. In order to do this, a FS was proposed and designed. The most suitable method for a converting categorical scale to numerical values is a fuzzy logic-based processing [4, 6]. The developed FS requires data such as follows:

- loudness scaling results for NH (normal hearing) persons – presented as the input membership functions,
- loudness scaling results for a given patient – each loudness scaling result represents a vector of three parameters (loudness level of the test signal, frequency band, selected loudness category),
- knowledge concerning interpretation of difference between results obtained for the examinee and NH persons (fuzzy logic rule base),
- output membership functions, which describe all possible differences between the examinee and NH loudness scaling results.

One of the most important information for the developed FS is the knowledge of LST results for NH people. This knowledge is represented in the FS by input membership functions. Because seven loudness categories are used in the LST (LGOB test), seven fuzzy sets per each frequency band are defined. Each fuzzy set is described by one membership function. In order to obtain these functions, 51 NH students were examined. An example of the input membership functions for one frequency bands is presented in Fig. 2.

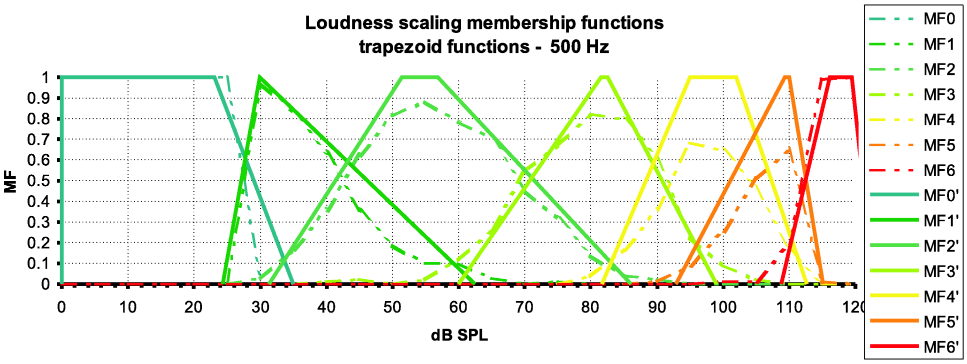


Fig. 2. Example of membership functions approximation with trapezoid functions.

In the process of predicting a membership functions shape, a very important assumption was done that the membership function conforms to the probability density function features. During the calculation process, two types of functions were taken into consideration: Gaussian (normal distribution function) and the trapezoid functions. The normal distribution function may be assumed in case the membership function shape is unknown, however the Gauss function never reaches zero value. In the fuzzy system case it means that each element belongs to all fuzzy sets (overlapping each other). In consequence, a fuzzy system performs more operations, because every rule is activated each time and thus a defuzzification procedure is more complicated. The trapezoid membership function shape is the most frequently used. This type of function requires only four parameters (trapezoid vertices). In a particular case, the trapezoid can be reduced into a triangle. When comparing Pearson test results for the Gaussian and trapezoid shapes of member-ship functions performed in this particular study it can be concluded that the trapezoid ones are better fitted than Gauss functions to the membership function shape prediction process [6].

Comparing the LST results on a seven point scale, 13 types of differences can be defined. Both the negative and positive difference means hearing impairment, but in addition – positive differences usually denote a loudness recruitment problem. On the basis of these differences thirteen output membership functions were created (see Fig. 3) [3].

An appropriate fuzzy processing based on rules was defined in the fuzzy rule base (FR). In this case two input variables were defined:

- Norm – represents the LST results for NH person,
- Exam – represents the LST results for the currently being examined person.

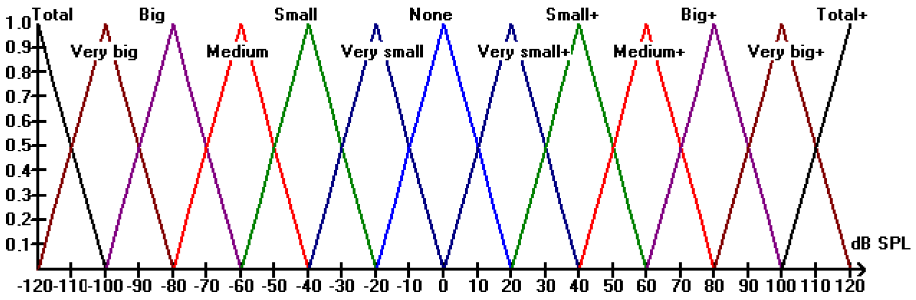
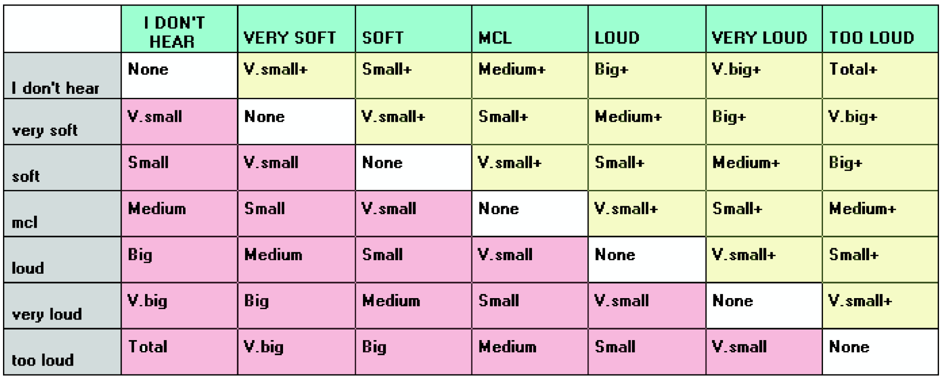


Fig. 3. Output membership functions.

Because each variable uses the same loudness category scale, the variable which represents an examinee, uses labels written in capital letters. In the developed FS a simple FR base was defined (Fig. 4). If for the same test signal LST results for the examinee and NH people are the same, the FS activates a rule with the output label "no difference". If such a difference is equal to one category, the FS activates a rule with the output labeled as "very small". If the difference equals two categories, the FS activates a rule with the output labeled as "small", etc. Experts from The Institute of Hearing Physiology and Pathology in Warsaw checked the rules proposed [2].



	I DON'T HEAR	VERY SOFT	SOFT	MCL	LOUD	VERY LOUD	TOO LOUD
I don't hear	None	V.small+	Small+	Medium+	Big+	V.big+	Total+
very soft	V.small	None	V.small+	Small+	Medium+	Big+	V.big+
soft	Small	V.small	None	V.small+	Small+	Medium+	Big+
mcl	Medium	Small	V.small	None	V.small+	Small+	Medium+
loud	Big	Medium	Small	V.small	None	V.small+	Small+
very loud	V.big	Big	Medium	Small	V.small	None	V.small+
too loud	Total	V.big	Big	Medium	Small	V.small	None

Fig. 4. The rule base.

3. Results of the fuzzy logic based loudness scaling test

The first step in the verification process of the designed method for LST results processing was to check correctness of the obtained HD characteristics. In this case, the obtained characteristics were compared with the characteristics calculated with standard method based on an average LST results for NH people. The comparison has shown that the HD characteristics obtained on the basis of the designed FS are in a good accordance with expected results, which was checked using thorough statistical analysis [6].

The main inconvenience of the LST is its long duration. The average test duration can be even 10 minutes per ear. Too long test duration is tiring for a hearing impaired (IH) person and may influence the results. This was the reason to find out the way to shorten the test duration and to save results reliability. The most intuitive idea seems to cut down the number of test signals. In this case, only the most characteristic test signal per each loudness category could be selected. This implies that only seven different test signals per each frequency band during the test could be used. In this case the test duration could be shortened to about 4 minutes per ear (more than twice). The test signal level which corresponds to the membership function maximum value is a good candidate to be a selected as the test signal. It means that loudness level of these test signals were chosen during the extensive tests with NH people.

The designed shortened loudness scaling test (sLST) was verified. In the verification process a group of twenty normal hearing students and three HI persons took part. First the NH students were examined with the standard LST and a few minutes later each of them performed the shortened LST. During the tests time was measured. Comparing test results it can be observed that obtained loudness scaling characteristics in a shortened mode are very similar to results gathered in a standard mode (Fig. 5). Times achieved in a shortened mode of LST are more or less twice shorter than in a standard mode (e.g. 9.5 min for standard LST and 5.5 min for sLST).

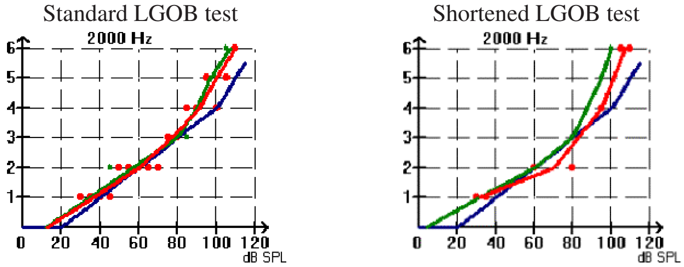


Fig. 5. Examples of loudness scaling results obtained in standard and shortened mode for NH students.

In the case of the HI person, each type of LST was repeated several times. The aim of these examinations was to check how the loudness scaling characteristics for the patient in a period time is changing. Figure 6 presents examples of the LST results collected within two weeks. The solid lines represent results obtained in the standard mode and

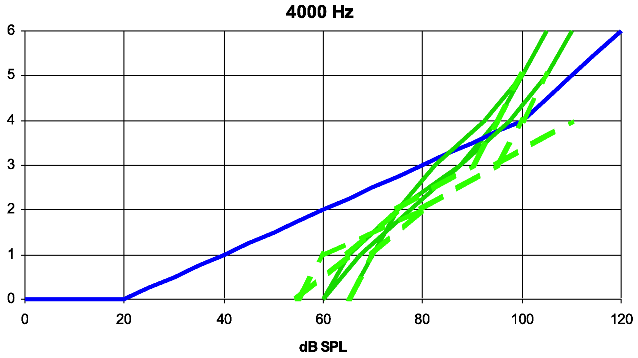


Fig. 6. Examples of loudness scaling results obtained in two loudness scaling test modes for the same hearing impaired person, the solid line – standard test LGOB, the dashed line – shortened LGOB test.

the dashed lines represent results obtained in shortened mode. It can be observed that the loudness scaling characteristics obtained in a standard mode are changed in the similar way as the ones obtained in a shortened mode. In this case examination time was also measured. The proportion between duration of the standard mode and the shortened mode is the same as in the normal hearing people case.

4. Conclusions

Utilizing fuzzy logic for processing of LST results approached two purposes of this study: flexible and effective method for calculating HD characteristics was designed, and the shortened LGOB test was created. The designed fuzzyLGOB converter allows calculating precisely a HD characteristic which is useful for both making hearing impairment approximate simulation and for hearing aid fitting. From the formal point of view utilizing the artificial intelligence method for processing loudness scaling test results, expressed in loudness categories, is more correct than approximate calculation of the HD characteristics on the basis of average results for NH people. The designed method is easy to implement and can be updated to other frequency bands or different loudness category scale. Additionally, based on the statistical analysis of loudness scaling results for NH, it has been become possible to shorten the LST duration more than twice. It means that in a much shorter time it is possible to obtain reliable HD characteristics.

Acknowledgment

The presented research work was supported by the Polish Ministry of Science and Higher Education within the Grant No. 3 T11E02829.

References

[1] ALLEN J.B., HALL J.L., JENG P.S., *Loudness growth in 1/2 octave bands (LGOB) – A procedure for the assessment of loudness*, J. Acoust. Soc. Am., **88**, 2 (1990).

[2] CZYŻEWSKI A., SKARŻYŃSKI H., *Multimedia Applications for the Hearing Impaired*, Archives of Acoustics, **32**, 3, 491–504 (2007).

[3] GELFAND A. STANLEY, *Essential of Audiology*, Thieme, New York 1997.

[4] KOSTEK B., *Soft Computing in Acoustics, Applications of Neural Networks, Fuzzy Logic and Rough Sets to Musical Acoustics, Studies in Fuzziness and Soft Computing*, Physica Verlag, Heilderberg, New York 1999.

[5] PLUVINAGE V., *Clinical measurement of loudness growth*, Resound Corp. Redwood City, CA.

[6] SUCHOMSKI P., *Employing Fuzzy Logic To Processing Of Loudness Scaling Test Results*, Journal of the International Telemedicine Academy, **1**, 2, 33–43 (2006).

[7] VALENTE M., *Hearing Aids: Standards, Options and Limitations*, Thieme Medical Publishers, Inc., New York 1995.