A DIGITAL MODEL FOR COCHLEA CHARACTERIZATION [1]

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Abstract: A digital scattering cochlea model that simulates Kemp echoes, in their impulse response, and from which a characterization of the cochlea can be made, is presented. The transfer function of the cochlea is estimated through Youla's ARMA system identification technique, and its spectrum is compared to that of Kemp echoes recorded from human ears.

INTRODUCTION

Cochlea modeling has been the subject of many studies for decades and several models exist in the literature, each one describing one or few particular functional aspects of the cochlea. However, most of these models are not directly appropriate for Kemp echo phenomenon since the latter is based on the incident and reflected pressure waves in the cochlea [1, 2]. Hence, a treatment in terms of scattering variables is the most relevant. We recall that Kemp echoes are acoustical signals emitted by the ear as a result of acoustic stimulation (Figure 1). Because there are significant differences in the Kemp echoes for normal versus certain types of damaged ears, it is felt that the Kemp echoes can provide a noninvasive way to quickly and easily characterize some types of damages to the inner ear. Furthermore, these emissions can be a reliable technique for demonstrating objectively the presence of normal activity in the cochlea, detecting changes in its functioning, as well as detecting hearing loss of noncochlear origin since, in this case, the echoes remain normal [3]. In light of these experimental findings, we developed a cochlea model that is able to regenerate Kemp echoes. The structure of the model is such that the geometrical and mechanical characteristics of the cochlea are embedded in the lattices composing the model, thus allowing a systematic extraction of these characteristics.

SUBJECT AND METHODS

The proposed digital scattering cochlea model is based on the unidimensional transmission line model into which nonuniform and loss properties are incorporated. It is obtained by rephrasing the model equations in terms of incident and reflected waves and digitizing the resulting equations in both space and time. The resulting structure is a cascade of digital lattice filters (Figure 2) where each lattice corresponds to one section of the cochlea. The lattice filters are described by their transfer scattering matrices whose entries are functions of the geometrical and mechanical properties of the cochlea [4].

To be able to use the digital model for cochlea characterization, its transfer function, assumed stable, minimum phase, and of unknown order, must be estimated. Kemp echoes (Figure 1), recorded from human ears and considered here as the impulse response of the cochlea, are employed as the output signal in a new ARMA system identification technique developed by Youla [5]. This technique is deterministic and utilizes the theory of positive real and bounded real functions and Richard's theorem, the concept of degree reduction, and determines both the order and the predictor coefficients of a stable digital ARMA(n,m) filter with a minimum phase rational transfer function. Here n and m are the degrees of the numerator and the denominator of the transfer function. The first 175 data points of Kemp echoes are suppressed because they represent the response of the middle ear which is not included in the model. The echoes are then normalized with respect to the largest data point in order to make its magnitude less than one. This is because Kemp echoes, in our model, play the role of a reflection coefficient used in transmission line theory.

RESULTS

The results of the estimation show that the cochlea is an ARMA(16,32). To measure the accuracy of this method, we compare the spectra of Kemp echoes and the estimated transfer function. The spectrum of the former is obtained by performing a Fast Fourier Transform on the data samples and the spectrum of the latter is obtained by evaluating the function on the unit circle in the interval $[0, 2\pi]$, which is then sampled into 850 points to match

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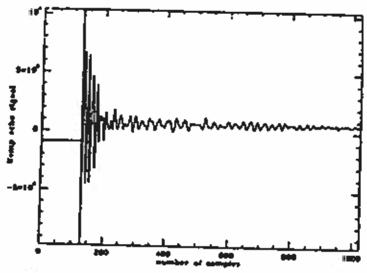

Figure 1: Kemp echo signal

the number of Kemp echo data points. Figures 3 and 4 show that the estimation technique is able to reproduce the magnitude of the transfer function accurately. The presence of a smaller number of oscillations in the estimated spectrum, compared to Kemp echo spectrum, is most likely to be due to the linearity of the model, whereas the ear exhibits nonlinearities.

DISCUSSION

In this paper we presented a digital scattering cochlea model that was able to simulate the response of a human ear to an acoustic stimulation. By using experimental data recorded from human ears and an ARMA system identification technique, we were able to identify the model as an ARMA(16,32). The technique reproduced accurately the magnitude of the spectrum of Kemp echoes. In the case of the phase, the method was able to reproduce the envelope, but not the rapid oscillations that are present in the phase of the Kemp echo spectrum. The discrepancies are mostly due to the fact that the technique estimates a minimum phase. To reproduce the actual phase, one can insert all pass factors. The results obtained with this model are in accordance with the findings of P. Van Dijk, from the institute of Audiology, the Netherlands, on spontaneous acoustic emissions of the ear. The spectrum of these emission, measured by P. Van Dijk, was found to contain up to 16 emission frequencies and since each emission frequency requires at least a second order system, a 32 degree system, as is the case with our cochlea model, would be able to generate all of the 16 emission frequencies.

References

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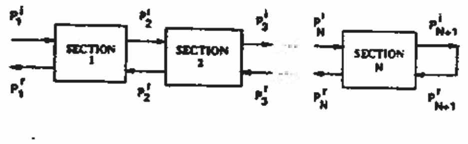

Figure 2: A cascade of cochlea sections.

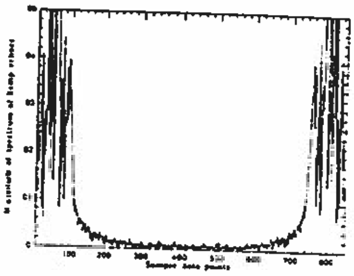

Figure 3: Magnitude of the Kemp echo spectrum.

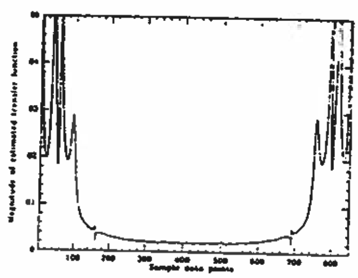

Figure 4: Magnitude of the estimated spectrum.

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