INVESTIGATION ON MISSING FUNDAMENTAL BY A COCHLEA MODEL GENERATING SPONTANEOUS DISCHARGE

T. Matsuoka , T. Hoshi

Dept. of Electrical and Electronic Engineering, Utsunomiya University,

Utsunomiya, Japan

Abstract-**It is considered that the pitch(f_0) is produced in auditory centers when we hear a complex tone of f_1 = n f_0, and f_2 = (n+1) f_0 . f_0 is known as missing fundamental. By a cochlea model we try to make clear the mechanism how missing fundamental is generated. The following signal is applied to the cochlea model. a_1 sin (2ðf$_1$ t) + a_2 sin (2ðf$_2$ t) . We make an aggregated autocorreleogram of output pulse trains from a cochlea model. We investigate methodically the relation between the information of missing fundamental in the output pulse trains and the values a_i , and n, k in f_1 = n f_0, f_2 = (n+k) f_0 by the aggregated autocorreleogram.**

***Keywords* – Missing fundamental, spontaneous discharge, cochlea model, aggregated autocorreleogram**

. INTRODUCTION

It is known that most of neurons perform integral pulse frequency modulation (abbreviation IPFM) with refractory period (RP). Refractory period consists of absolute refractory period (ARP) and relative refractory period (RRP). We have investigated the nature of IPFM system with RP and have made clear followings.

Phase - lock phenomenon occurs for an input periodic signal { sin(2ðf_1t) }[1].

The information of f_0 explicitly appears in the aggregated autocorrelogram of pulse trains from the IPFM systems with ARP[2]. (It was made clear experimentally that ARP plays an important role for generating phase-locked pulses)

A pulse train is from the IPFM system with ARP for an input signal { sin(2ðf_1t) }.

Another pulse train is from the IPFM system with ARP for an input signal { sin(2ðf_2t) }.

where f_1 = n f_0, f_2 = (n+1) f_0

f_0 is named missing fundamental

It is also known that primary auditory nerves (PAN) in the peripheral auditory system perform IPFM and missing fundamental phenomenon occurs in the auditory system[3]. So, we make a cochlea model and investigate how the information of missing fundamental is contained in pulse trains in the peripheral auditory system.

. A COCHLEA MODEL

Fig.1 is the block diagram of a cochlea model [2]. The cochlea model consists of a model of Basilar Membrane (BM) and a model of Hair Cell Primary Auditory Nerve(HC PAN). The model of Basilar Membrane transforms an input sound wave into a progressive wave on the Basilar membrane. The model of Hair Cell Primary Auditory Nerve is a neural network which transforms the displacement velocity or the displacement of the Basilar Membrane into pulse trains.

Fig.2 is a model of Basilar Membrane-Hair Cell Primary Auditory Nerve of type I. The part (Hair Cell Primary Auditory Nerve) of this model is a neural network based on physiological observations. An input layer's unit of the neural network is an inner Hair Cell. Each input layer's unit detects the displacement velocity of the Basilar Membrane at each position on the Basilar Membrane. The unit also performs half wave rectification. The output layer's units are Primary Auditory Nerves of type I which perform IPFM with Absolute Refractory Period and generate pulse trains. The name of Neural Network (NN) of 200Hz of type I is applied as follows. The input layer's unit in Neural Network of 200Hz is located at the position of the BM where the envelope peak of the progressive wave of 200Hz appears. Neural Network of 400Hz, Neural Network of 500Hz, etc. are named in the same manner.

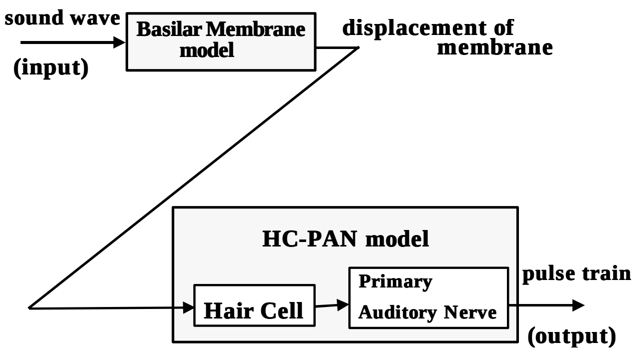

Fig.1. Block diagram of a Cochlea model

IPFM : Integral Pulse Frequency Modulation

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Investigation on Missing Fundamental by A Cochlea Model Generating Spontaneous Discharge	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Department of Electrical and Electronic Engineering Utsunomiya University Utsunomiya, Japan	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
5

Output layer's units contain the electric power source such as generates spontaneous discharge. For no input signal to an output layer's unit, interval histogram of spontaneous discharge of the unit is of exponential shape. Synaptic weights of NN are fixed. It supposes synaptic weights which are originally fixed or synaptic weights of NN which finished unsupervised learning.

The values of parameters in the cochlea model are followings.

absolute refractory period of primary auditory nerve
1.0 msec

threshold 20.0 mV

frequency of spontaneous discharge 100 events/sec

Fig.3 is the block diagram of a model of Hair Cell – Primary Auditory Nerve of type I (with spontaneous generator).

. METHODS

A following complex tone signal is applied to the cochlea model.

Ó a_i sin (2ðf_i t + $è_i$)

where max i = 2, $è_i$ = 0, f_1 = n f_0, f_2 = (n+k) f_0

i.e. a complex tone signal is

a_1 sin (2ðf_1 t) + a_2 sin (2ðf_2 t)

We get one group of output pulse trains from NN of f_1 Hz and another group from NN of f_2 Hz(see Fig.4). To see periodicity and structure of pulse trains, we make each autocorreleogram of each group of pulse trains. To see the information of missing fundamental in pulse trains, we make an aggregated autocorreleogram of the autocorreleograms.

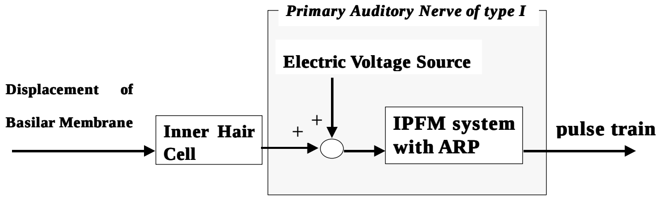

Fig.3. Block diagram of a model of Hair Cell – Primary Auditory Nerve of type I (with spontaneous discharge generator).
IPFM:Integral Pulse Frequency Modulation
ARP:Absolute Refractory Period

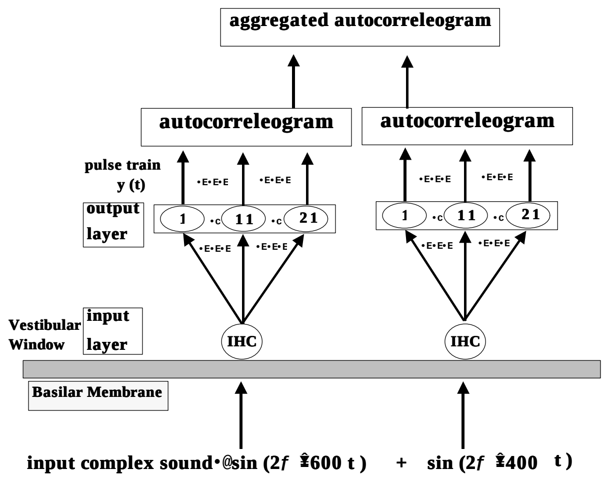

Fig.4. Aggregated autocorreleogram
IHC: Inner Hair Cell

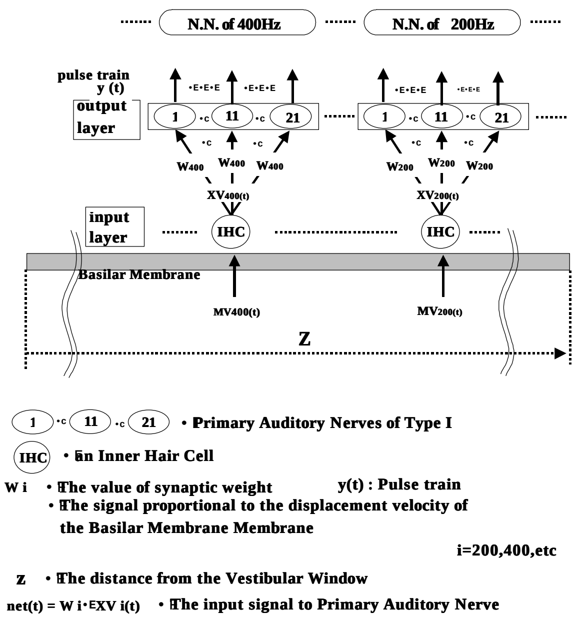

Fig.2. a model of BM-IHC PAN(PAN of Type I)

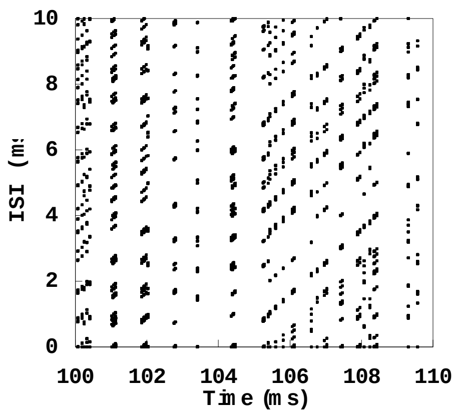

Fig.5. The aggregated autocorreleogram of autocorreleograms

. RESULTS

Fig.5 is the aggregated autocorreleogram(where f_1=1200Hz, f_2 =1400Hz). Fig.6 is the interspike-interval histogram (bin size 0.1msec) of the aggregated autocorreleogram. Peakes of the interspike-interval histogram apear at n times 5 ms(n=1,2,...) in the interspike-interval histogram(see Fig.6). It means that in pulse trains from NN of f_1 Hz and NN of f_2 Hz there are many pulses whose intervals equal the period (5msec) of missing fundamental f_0 (f_0 = 200Hz). To extract missing fundamental, we make normalized interspike-interval histogram (Fig.7). Results of extracting missing fundamental are in table 1. Results in changing the value of a_i also are shown there.

Missing fundamental is extracted more clearly in case of a_1/ a_2 = 3/1 or 1/3 than in case of a_1/ a_2 = 1/1.

The smaller k is, the more clearly missing fundamental is extracted. It suggests that the maximum value of k exists.

. CONCLUTION

We made a cochlea model whose primary auditory nerves generate spontaneous discharge too. To see the information of missing fundamental, we have made the aggregated autocorreleogram of the output pulse trains. The relation between the information of missing fundamental and a_i, n, k, in f_1 = n f_0, f_2 = (n+k) f_0 is investigated systematically.

It is found experimentally that missing fundamental is extracted clearly in case of a_1/ a_2 = 1/1 (in a_1 sin (2ðf_1 t) + a_2 sin (2ðf_2 t)) and the maximum value of k (in f_2 = (n+k) f_0) exists.

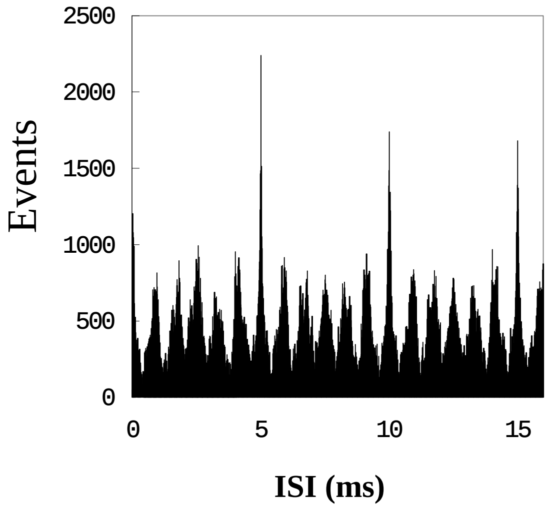

Fig.6. The interspike-interval histogram of the aggregated autocorreleogram (bin size 0.1ms) an input signal sin(2ð 1200t) + sin(2ð 1400t)

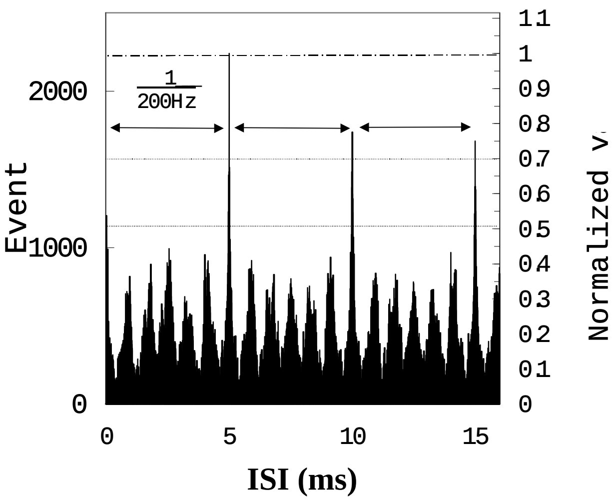

Fig.7. Normalized interspike-interval histogram (thresholds are 0.5 and 0.7)

Table1 Extraction results of missing fundamental

f_0=200Hz

No.	f_1 [Hz]	f_2 [Hz]	n	k	a_1	a_2	extracted missing fundamental[Hz]	
							threshold 0.7	threshold 0.5
1	1200	1400	6	1	1	1	200	nothing
2					3	1	200	200
3					1	3	200	200
4	1200	2200	6	5	1	1	nothing	nothing
5					3	1	nothing	nothing
6					1	3	200	200
7	2000	2200	10	1	1	1	nothing	nothing
8					3	1	200	nothing
9					1	3	200	200
10	2000	2600	10	3	1	1	nothing	nothing
11					3	1	200	nothing
12					1	3	200	200

REFERENCES

[1]MATSUOKA, T. and MORITA, H. ,“The occurrence of synchronous pulse train of 1 pulse output per n periods of the input signal by IPFM with absolute refractory period”, IEICE Trans. Information and Systems, Vol.J72-D-II, No.6, pp.974-977, June 1986 (In Japanese)

[2] T. Matsuoka and Y. Ono, “On synchronous phenomenon by integral pulse frequency modulation with a refractory period”, Proc. 9th International Conf. Biomedical Engineering, pp.269-271, Singapore,1997.

[3]K.Hiwatashi:"Biological Information Science", CORONA Co. Ltd., pp.28-30, 1980 (In Japanese)