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Identification and processing of in-ear acoustic signals

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Abstract. Hearing is the sound depiction of the world for human beings. The ear, or in other world, the peripheral organ of hearing, is an important physiological structure and basis to produce hearing. In order to learn more about hearing organs, the first thing required to know is how hearing is formed, as well as how sound is perceived by us. For this purpose, this paper will examine the matter of identification and processing of in-ear acoustic signals. The main content of this paper are principles of sound, hearing, and signal encoding, as well as their usage in a model which describes the neuron system in cochlear nucleus. In addition, this paper puts forward an application of in-ear signal identifying in hearing aids and cochlear implants by using the convolution signal encoding mode to improve the sound recognition function of these devices and further improve the lives of the hearing impaired. In the end, basic conceptions and related knowledge are organized in this paper. The meanings and problems of this paper are also mentioned in the last section.

Keywords: sound, hearing, signal, convolution.

1. Introduction

Hearing is the sound depiction of the world for human beings. The ear, or in other world, the peripheral organ of hearing, is an important physiological structure and basis for the production of hearing. In the formation of hearing, all parts of the ear play a vital role, like a precision instrument. And once there is a problem in one part of this instrument, humanity will lose the right to enjoy beautiful vocals and sounds. In order to learn more about hearing organs, the first thing required to know is how hearing is formed, as well as how sound is perceived by us. For this purpose, this paper will examine the matter of identification and processing of in-ear acoustic signals.

At first, this paper basically introduces sound and hearing. When talking about sound, this paper will focus on describing its physical characteristics and propagation mode from the perspective of sonic signals. As for hearing, this paper will introduce in detail the biological structure of the human ear, which leads to the formation of human hearing. Since the sound is mentioned as a kind of signal, this paper will move on to the introduction of signal identifying in the second part. This section focuses on two aspects: signal transmission and signal encoding methods. Convolution encoding is highlighted in section 2.2 for it will be the core algorithm of the in-ear acoustic signal identifying stimulation model showed in the next section. In section III, this paper picks up a model which describes the neuron system in cochlear nucleus in order to give an example of human hearing stimulation using circuit models and convolution signals to simulate the process of receiving and

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recognizing sound signals in the cochlear nucleus. In the end, this paper puts forward an application of in-ear signal identifying, which is hearing aid and cochlear implants.

For the hearing and sonic signal research industry, this paper provides the idea of using the convolution signal encoding mode to improve the sound recognition function of cochlear implants and hearing aids for the purpose of improving the performance of these devices and further improve the lives of the hearing impaired.

2. Sound and hearing

2.1. The sonic signal

Sound is a wave produced by the vibration of an object. It is a wave phenomenon that propagates through a medium (air or solid, liquid) and can be perceived by human or animal hearing organs.

In physics, sound is produced by the vibration of objects, and the object that is making sound is called a sound source. The number of times an object vibrates in a second is called frequency, and the unit is hertz(Hz), the letter Hz. The human ear can hear the sound of 20 ~ 20000Hz, the most sensitive is the sound between 200 ~ 800Hz [1]. The propagation speed of sound in different media is generally solid> liquid> gas, and the propagation speed of sound is related to the type of medium and the temperature of the medium. Normally, the speed at which sound travels in the atmosphere is 340m/s [2].

Sound is a pressure wave [3]. When playing musical instruments, knocking at the door or knocking on the table, these movement will cause a rhythmic vibration of the medium (air molecules), causing the air to produce dense changes and form waves, and that is where the sound waves come from. As a wave, the frequency and amplitude become important attributes to describe it. The size of frequency corresponds to what we usually call pitch, and the amplitude affects the size of sound. Sound can be decomposed into superposition positions of sine waves of different frequencies and intensities. This transformation (or decomposition) process is called Fourier transform. Therefore, the general sound always contains a certain frequency range. The propagation of sound is interpreted by quantum mechanics as the movement of atoms, forming sound waves. Since sound is a wave, it can be thought of as a signal that can propagate information, that is, a sonic signal.

2.2. Biological hearing

By studying sonic signals and hearing, research of ear structure is the thing that must be done. Figure 1 shows the structure of the human ear.

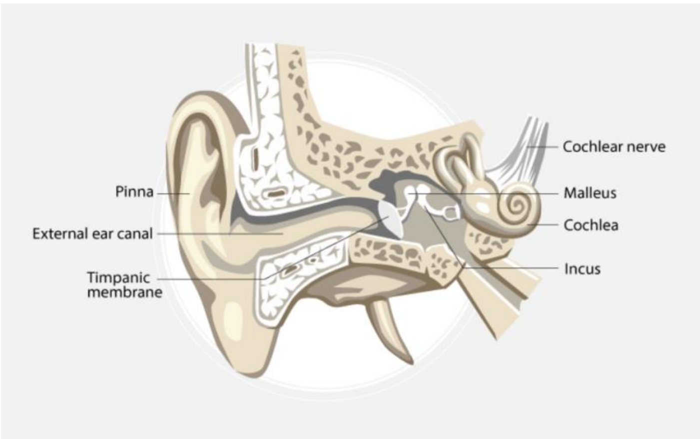

Figure 1. Human ear structure.

The outer ear, which is all the outer pinna and ear canal that we can see, plays the role of collecting and transmitting sound. The sound transmission structure of the middle ear mainly includes the tympanic membrane and the auditory bone chain. The eardrum is similar to the drum face of the drum, and when the sound is transmitted, it causes the vibration of the eardrum, which is then transmitted to the ossicles. The ossicles are made up of three bones, the hammer bone, the anvil bone, and the stapes bone, which are connected to the eardrum membrane, while the stirrup bone is in contact with the oval window of the cochlea. After the vibration of the eardrum, it will drive the vibration of these three small bones, and finally the oval window membrane will be vibrated by the stapes bone, and the sound energy will be transmitted to the cochlea. The cochlea, vestibule, and semi-circular canal together make up the inner ear, and the cochlea is responsible for hearing, while the vestibular and semi-circular canals are responsible for balance. When the cochlea receives sound energy from the osseoakis of hearing, it stimulates the hair cells in the cochlea, which convert this energy into a bio-electric form, which is then transmitted to the brain by the auditory nerve behind the cochlea to form hearing [4].

3. Signal identifying

3.1. Signal transmission

The basic modes of signal transmission are analogy and digital. Analog signal [5] transmission is a transmission method of transmitting information by analogy signal in a transmission medium. Analog transmission is a kind of transmission without considering its content. This is a way to transfer energy. The energy must be lost in the transmission process, and the signal strength of the analogy signal is amplified by the amplifier. In long-distance transmission, it is necessary to amplify its energy by one level, but its noise will also increase, which is called distortion.

On the other hand, digital signal transmission is a method that transmits information as a digital signal in a transmission medium [6]. Digital transmission also requires signal amplification during transmission. The digital signal uses a threshold voltage composed of circuits to simply reassemble and regenerate the received signal to generate a new signal that eliminates attenuation or distortion.

3.2. Signal encoding methods

Analog signal is a form of propagation energy, which refers to a continuous (uninterrupted) signal in time (uninterrupted), and the magnitude of the value is also a continuous and uninterrupted change (traditional audio signal, video signal). If a sound wave causes the medium it passes through to vibrate, the sound wave can be measured in frequency (in cycles per second or in hertz).

Digital data is transmitted by the methods of electrical pulses, and uses a single pulse to represent a bit by one-to-one correspondence . Its efficiency is very low, so a variety of coding schemes have been developed to transmit digital data more efficiently using electrical pulses. The result is a significant increase in throughput. This is similar to sending messages using semaphores. For example, "signal flag raised" means 1, and "signal flag lower" means 0. A more efficient encoding scheme is to "raise or lower the signal flag only when binary 1 appears".

In digital transmission systems, convolution encoding is a very efficient way to encode [7]. Convolution can be understood from the perspective of input signal: how each sampling point of the input signal is contributed to multiple output signal sampling points, that is, after each input signal component enters the linear system, multiple translation and scaling versions of the pulse reaction will be generated, and the output result is the synthesis of the translation and scaling version of the pulse reaction corresponding to each signal component; Understand from the perspective of the output signal: how the sampling point of each output signal obtains information from the many input signal sampling points. That is, for each output signal, multiple input signals will contribute their impulse response, and the output result is a linear weighting of the corresponding impulse response.

The following parts of this paper will introduce the application of convolution coding in the recognition of in-ear sound signals using an in-ear signal processing model as an example.

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4. In-ear Acoustic Signal Identifying Stimulation

In the in-ear neuron system, the cochlear nucleus (CN) is the lowest nucleus of the auditory center and is the only known destination for all human-transmitted nerves from the auditory periphery [8]. Information processing in the nucleus of the cochlea is the first link in the central process of auditory information. Studying the reactive characteristics of neurons in the cochlear nucleus is important to elucidate the mechanism of action of sound signals in the auditory system. This paper mainly takes a model which describes the neuron system in CN as an example to introduce.

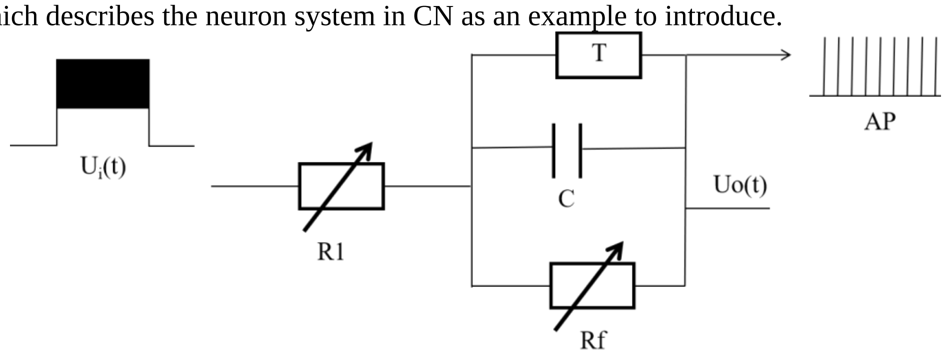

Figure 2. Model diagram.

Most cochlear nuclei neurons receive single or multiple synaptic ends that transmit signals from auditory fibers. Around these synapses there are many fibers that innervate the presynaptic membrane and postsynaptic neurons, regulating the release of neurotransmitters and changes in membrane properties. The membrane properties of a neuron can be described by bio-electric properties, such as thresholds, capacitance, membrane conductance (membrane resistance), and time constants. From this, we reduce the neuron to a circuit loop structure diagram (Figure 2). C, Rf are seen as the membrane capacitance and membrane resistance of the postsynaptic neuron, and R1 is seen as the presynaptic resistance that simultaneously controls the influence of the input on the postsynaptic neuron. When the input signal is passed through this loop, the film capacitance acts similarly due to the postsynaptic film an integrator equivalent to acting with the convolution signal H(f) to obtain the output signal [9].

$$U_0(t) = U_i(t) * H(t) = \int_0^t U_i(\tau) \cdot \left(\frac{1}{R_1 C} \cdot e^{-\frac{t-\tau}{R_f C}} \right) d\tau \tag{1}$$

When the input electrical change reaches the action potential generation threshold through the time integration of the film capacitor, an action potential is generated; After the neuron generates the action potential, the membrane potential is quickly reset to the resting level, and then the input signal is integrated again to repeat the previous action potential generation process. This is repeated and the neuron transforms the input signal into action potentials generated at different times at a relatively stable threshold. Equation (2) is exactly the coding model for this process.

$$T_0 \pm A\left(1 - e^{-\frac{t}{a}}\right) = \int_0^t U_i(\tau) \cdot \left(\frac{1}{R_1 C} \cdot e^{-\frac{t-\tau}{R_f C}} \right) d\tau \tag{2}$$

The time coding of the input information by the neuron model is related to the time constant of the neuronal membrane charge, the initial and the additional threshold potential, the intensity of the input information, and its time compilation of the input information. The code can be set according to actual needs. Adjusting the values of each parameter can obtain different sequences of action potentials, that is, the time coding characteristics of the action potential can be adjusted by adjusting the values of each parameter.

This neuron model can well simulate the response of various neurons by changing the settings of some parameter values. When only the membrane characteristic parameters are changed, and the parameter values that affect the threshold are not changed, the three neurons of the primary reaction type, the comb type, and the vocal initiation type can also be transformed into each other. That is to say, these neurons in CN are essentially the same, follow the same coding method, but due to the

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characteristics of each neuron, different responses to the input signal lead to different action potential sequences. But changing the intensity of the input signal has little effect on the type of neuronal response. Thus, the CN neuronal response characteristics are mainly determined by the characteristics of the neurons themselves.

5. Application

When our hearing declines for various reasons, the first thing that has to be done is to seek the help of a doctor. Some hearing loss problems can be solved by drugs or surgery, and those hearing problems that can not be solved need to be intervened through hearing aids and cochlear implants.

Hearing aids are a class of acoustic amplifiers used to solve the problem of hearing impairment in people with hearing loss. Hearing aids are mainly composed of microphones, amplifiers and microphones. The main role of the microphone is to collect sound and the function of the amplifier is to process and amplify the electrical signal according to the relevant settings, and the processed sound is then converted into an acoustic signal output by the microphone. Common types of hearing aids are back ear machine, in-ear machine, ear canal machine, etc., which can be selected according to the different requirements of patients. The hearing aids was shown in figure 3.

Figure 3. Hearing aids.

Not all hearing loss can be compensated for by hearing aids, and for patients who cannot get a hearing lift through hearing aids, there is an option to intervene with a cochlear implant.

Cochlear implants use electrical stimulation of the auditory nerve to simulate normal cochlear hearing [10]. First, the microphone on the outside machine converts the sound pressure change in the air into a voltage signal, the voltage signal is amplified and sampled and enters the speech processor (usually its core is a digital signal processing chip), the speech processor is responsible for encoding the obtained sampling signal (including acoustic signal coding and control instruction coding), and then the radio frequency transmission circuit modulates the coding result of the speech processor to the RF carrier signal (generally commercial frequency band is 5~50MHz range). The RF signal follows the wire to the transmit coil fixed on the outside of the scalp (the transmit coil and the receiving coil implanted under the skin attract each other through a magnet at their respective centers to fix the position of the transmitting coil), through the electromagnetic coupling between the coils, the encoded signal enters the implanted body, and then decodes in the implant-specific chip to the value of the stimulus parameter to be generated on each electrode, and the simulator is responsible for generating the current corresponding electrode according to this parameter value, and the current reaches the electrode array that has been pre-implanted in the cochlea along the wire. Stimulation is generated on the corresponding electrode contacts.

6. Conclusion

Through the above research, the following conclusions are obtained in this paper. In the first and second section, this paper organizes basic conceptions and knowledge of sound, hearing and signal. Since sound is a wave, it can be interpreted as a signal, and that is why sound can be studied in the same way that signals can be studied. At the same time, because the human auditory nervous system also relies on electrical signals to transmit information, it can use the idea of signal transmission and reception to study hearing. After that, this paper describes a model of cochlear nuclei neuron system and demonstrates that it is effective and reliable. Finally, this paper gives the idea of using the similar way of the model mentioned above to improve the sound recognition function of cochlear implants and hearing aids.

Hope has been generated that a new method of improving the performance of these devices has been given in this paper. But so far it is feasible in theory, which means this method is lack of experiment to prove that it can be popularized in reality. In that case, further research goals have been set. The significance of this paper is to put forward the concept of using the principle of convolution coding to improve the performance of hearing aids, as a guidance of the industry.

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