Biosignals from the point of view of biophysics

Analog signal transmission

We call the indicated method of sensing , processing (amplification), transmission and registration of the signal analog , since all quantities here change continuously , even though their physical nature may change during the transmission of the signal.

In our example with a gramophone record, first some acoustic pressure will cause it a corresponding mechanical deflection of the microphone membrane. This mechanical deflection causes a voltage change on the microphone, the voltage changes are amplified by amplifiers whose output current moves the spade. When the record is played back, the mechanical movement of the gramophone needle is converted into electrical changes, which are amplified again and converted by the output of the amplifier into oscillations of the coil, vibrating the loudspeaker membrane, which causes changes in air pressure. These are further spread through space as an acoustic signal to the eardrum of the listener, which, like the membrane, converts them into the movement of the middle ear ossicles .

The essential thing in this chain of causes and effects is that, although the physical nature of the quantities is different, their course in time is similar, or analogous: the course of the mechanical deflection is analogous to the pressure that caused it . Similarly, the course of the generated voltage is analogous to this deviation, the course of voltage and current at the output of the amplifier is analogous to the input values, etc. The courses of all these quantities are therefore somehow analogous to the course of the investigated signal . According to this analogy, this method of processing is called analog (not analog!) and is characterized by the fact that all quantities representing the given signal change continuously in the given chain.

Concept of ideal analog transmission [edit | edit source]

In an ideal case, the course of the signal at the output of the entire chain would be completely analogous to the course at its input, i.e. it could differ only in its physical nature, and its course at the output would be a faithful representation of its original course. For example, we might fervently wish that individual analog quantities were proportional to each other: so that the instantaneous deflection of the membrane is directly proportional to the instantaneous acoustic pressure that caused it; so that the voltage at the microphone of the amplifier is directly proportional to its deflection; so that the output current of the amplifier is directly proportional to the input voltage; that the deflection of the speaker membrane is directly proportional to this current; so that the resulting sound pressure is directly proportional to this deflection; that the deflection of the ear drum is directly proportional to the acoustic pressure; etc. In such an ideal case, we could then express some output signal $y(t)$ in terms of the input signal $x(t)$ as

$y(t) = A \cdot x(t)$ (1)

where A would be the **constant of proportionality** .

Signal Gain

In the event that $x(t)$ and $y(t)$ would have the same physical character, i.e. they would be the same quantities – e.g. electric voltages, the constant A would represent a physically dimensionless quantity:

$A = \frac{y}{x}$ (2)

Both quantities x, y can be compared to each other. If we find that,

$y(t) > x(t)$ (3)

Then $A > 1$ (4)

We'll call this the number amplification. In our example, if both $x(t)$ and $y(t)$ represented the waveform of the input and output voltages, this would be voltage gain, because this concept of proportionality will express how mnay times this voltage is higher than the input voltage, in other words how many times the input voltage has been amplified.

Profit

Since in the case of amplification it is a proportional number, we preferably use **logarithmic units** to express it , known as **decibel** $[dB]$. Then we talk about the **gain**, for example an amplifier amplifying **the voltage** 1000 times will have a gain of 60 dB, because :

count $dB = 20 log \frac{U_2}{U_1}$ (5);

in the case of electric **current** :

count $dB = 20 log \frac{I_2}{I_1}$ (6);

and in case **of performance** :

count $dB = 10 log \frac{P_2}{P_1}$ (7).

Why do we multiply by twenty in the case of voltage or current, but only ten in the case of power? The answer is simple: because the power (with the same impedance) depends on the square of the voltage or current, and we calculate the logarithm of the square as twice the logarithm.

We have to think in a similar way in the case of **non-electric quantities** , e.g. when calculating the sound level from the ratio of sound **intensities** (sound intensity has the character of power - it is power related to a unit of area - therefore we will only multiply by **ten**). These facts must be carefully observed, otherwise we will commit significant order of magnitude errors - the amplifier with a gain of $60dB$, which we gave as an example a moment ago, will not amplify the power a thousand times, but a million times!

Loss, attenuation

If $y(t) < x(t)$ (8)

which is the usual case of passive line , in which there are losses during transmission , or with passive filters , etc., of course, we are not talking about signal amplification, but on the contrary, its attenuation , which we also express in decibels . The relations for the calculation are completely analogous to those above, except that we have to pay attention to the sign: we normally say that the signal loss during transmission was $10dB$, without mentioning the minus sign.

Conversion constant

If the quantities $x(t)$ and $y(t)$ have a different physical character, we cannot simply measure them in this way - we cannot say that the current $2A$ is twice the voltage $1V$ and it also depends on the chosen units. Therefore, the **proportionality constant** A in relations (1) and (2) has a definite physical dimension and it is not just a dimensionless number as in the case of amplification or attenuation. The corresponding physical dimension is obtained by dividing the physical units of the output and input signal. For example, if the input signal of the system is the voltage at the input of the amplifier, given in mV, and the output signal is the deflection of the stylus in cm, we give the conversion constant in $\frac{mV}{cm}$.

It is not customary to actually perform the indicated division, i.e. instead of the value $1 \cdot \frac{mV}{cm}$ we usually do not write $0,1 \cdot \frac{V}{m}$, but for practical reasons we keep both units in the given ratio. One might think of shortening the units: for example, when registering the pressure, one could adjust the conversion constant,$1 \cdot \frac{kPa}{cm}$ to $1 \cdot \frac{kN \cdot cm}{m^2}$ and then write $1 \cdot \frac{kN}{m^3}$, which also doesn't make any sense.

As a last example of this kind, let us consider an amplifier - current $\longrightarrow$ voltage converter, which reacts to a change in input current by $1mA$ by changing the output voltage by $1V$. In this case, we get the conversion constant $\frac{1V}{1mA}$, which is directly tempting to perform the indicated division according to Ohm's law and give the result 1Ω. But yes! After all, a mere resistance of size $1k\Omega$ can function as the converter just described: when the current changes by $1mA$ the voltage drop on it changes by $1V$. This reasoning is flawed in that such a resistor would probably not fit in place of the current converter in most cases, precisely because of its too large input resistance. And with a real converter, as a rule, its input and output impedances are different, so even in this last example, an attempt to modify the unit does not seem meaningful.

We will examine the **transmission characteristics in analog transmission in more detail in section 2.5.**

Calibration signal

In practically designed devices, it is customary to enable the introduction of a so-called **calibration signal** at the **input** of the entire system. For example, with EEG , such a signal can be a rectangular waveform or a single impulse with amplitude $100\mu v$ and duration (pulse width) $1s$. By writing such a signal on the output of the device - on moving paper - we can characterize the entire device and verify the actual value of its conversion constant, for both units in the given coordinate system (voltage and time) at the same time.

Let's note at this point that the originally rectangular signal will usually not appear as a pure rectangle at the output, but rather as some strongly distorted "rectangle", the sides of which will be formed by rounded curves, more precisely by exponential waveforms. The exact shape of this curvature is also important, as it informs us about the current settings of the parameters of the transmission chain, namely the settings of the time constant (affects the transmission of low frequencies) and the filter (limits high frequencies). We say that the signal has been distorted in its transmission path - and in this special case it is an intentional distortion , the main purpose of which is to suppress unwanted artifacts. In addition to this limiting effect, however, the set distortion affects and distorts the course of the desired signal , which is why it is necessary for the doctor who evaluates and describes the recording to take it into account.

However, the effect of such filters on more complex signal sequences is not completely trivial and therefore, to the displeasure of many, it is not possible to completely omit the relevant passages from the theory. Let us be comforted by the fact that we will eventually find a much wider application for the acquired knowledge than we initially expected.

Links

Source

- HEŘMAN, Petr. *Biosignály z pohledu biofyziky.* 1. edition. 2006. 63 pp. ISBN 80-902899-7-5.

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