Analog to digital and digital to analog conversion

Most medically significant biosignals have a continuous character, i.e. they can acquire practically arbitrary values from some interval. In contrast, today's computers are exclusively digital, i.e. they only work with discrete values. On the contrary, sometimes digital data from a computer needs to be converted to the value of a continuous quantity. The specific technical implementation is interesting, but not important for healthcare professionals. It is important that the healthcare professional knows roughly the principle and limitations.

Analog to digital conversion

Assume that a continuous voltage signal carries information in the value of its voltage . We will assume that the voltage can vary between *0* and *5* V. An analog (continuous) signal can in principle take on an infinite number of values. However, the price for this is a relatively high sensitivity to disturbances and noise of various origins. For example, a current from the electrical network (so-called hum voltage) can be induced on the line. A change in temperature leads to a change in the resistance of the conductors, electrical components age and their parameters change, etc. Digital signal, preferably binary (i.e. only e.g. *0* or *5 In*), on the other hand, is very resistant to these disturbances, because the noise level only rarely reaches such values that an error in interpretation occurs.

Now let's imagine that we want to measure this voltage and write it into memory when we have, for example, one byte. A common way is to assign the smallest value (*0) to the smallest voltage and the largest value (255*) to the largest voltage. Thus, in our case, for the digital representation *D* of the voltage *U* , the following will apply:

$$D = \text{ceil}(51 \cdot U)$$

, where the ceil function marks the entire argument part.

And here we come to the first limitation of analog-to-digital conversion. The value is rounded, so there is a certain small voltage that the converter does not distinguish. In our case, it is approximately *20 mV* (as an exercise, the kind reader can verify). The phenomenon when the converter loses information about small changes in the digitized signal is called quantization error.

Quantization error is very important in the study of deployment. If diagnostically significant changes in the biosignal are comparable to the quantization error, they will be suppressed during digitization.

Another weak point of analog-to-digital conversion lies in its own technical implementation. Common types of converters perform the conversion in such a way that the individual bits of the resulting digital number are determined sequentially. The theoretical problem of the change of the transferred value during the transfer is usually solved satisfactorily by technical means. The problem is that the conversion takes a relatively long time and is slower the greater the number of bits to be output, i.e. the smaller the required quantization error. In other words, if we want to digitize signals that change too quickly, the sensitivity of the measurement is limited for technical reasons and vice versa.

The last and potentially very important source of errors are changes in the parameters of the components in the converter (very precise voltage dividers, operational amplifiers,...). For new converters, this is guaranteed by the manufacturer, but in the case of use, for example, in research practice, it is desirable to continuously check the so-called linearity of the conversion.

Related to the issue of analog-to-digital conversion is the issue of sampling, i.e. actually the discretization of time and the limitation of knowledge about the voltage value only to values at given time points. An interesting task was the question of what is the smallest frequency of sampling (sampling) so that the sampled signal contains all the information from the original signal. The solution is known as the Shanon-Kotelnikov theorem, the Nyquist theorem or the sampling theorem, the result is surprisingly simple. It is sufficient that the sampling (sampling) frequency is twice the highest harmonic in the Fourier spectrum of the signal. However, for a number of technical reasons, this is not sufficient and a higher sampling frequency is usually chosen.

Digital to analog conversion

Digital conversion is quite complex in terms of principle and source of possible errors. Digital to analog conversion is much simpler. It is often about the control of relatively powerful components, where we only pay attention to safety elements.

In a number of applications, including medical ones, it is more advantageous to directly convert a digital signal to a desired physical quantity. The role of the D/A conversion is therefore taken over by e.g. the stepper motor (speed, displacement), switching on and off the heating element (heating) or control by quickly switching the state "on" and "off" (brightness regulation of LEDs).

Links

Footnotes

1. ↑ We talk about the voltage signal for the reason that it is usually best to work with such a signal. In addition, a number of biosignals are inherently voltage-based (ECG, EEG) and the sensors of other biosignals have an electrical voltage or current as an output.
2. ↑ This is not a completely random choice. This is the so-called TTL logic used in digital technology, where the *logical value 0* is assigned to a voltage of *0 V* and the *logical value 1* is assigned to a voltage of *5* V. Just for the sake of completeness, we mention that this is not a single system and, for example, personal computer processors use lower voltage levels.
3. ↑ This is one of the main reasons why it is problematic to use the audio inputs of a personal computer, e.g. to digitize most biosignals, and one must use more expensive hardware, e.g. measurement cards.
4. ↑ So, for example, in digital music, it should theoretically be enough for the recording sampling frequency to be *40 kHz* . Due to the quantization noise and the fact that we want to convert the signal back to analog on a less than ideal converter as a result, the sampling frequency of *44.1 kHz*(audio CD) is used more for end users, while for professional purposes much higher frequencies are used.

Links

- AD and DA converters at WikiBooks
- HÁZE, Jiří and Vladimír VRBA, et al. *Theory of mutual conversion of analog and digital signals* [online]. FEKT BUT Brno, Last revision 10.2.2010, [cit. 9/2/2013]. < https://www.umel.feec.vutbr.cz/MTVP/prednasky/AD_DA_scripta.pdf >.

Literature

HAASZ, Vladimír – SEDLÁČEK, Miloš. *Elektrická měření – Přístroje a metody.* 1. edition. Prague : ČVUT Publishing, 1998. ISBN 80-01-01717-6.