Teaching Signal Processing to the Medical Profession

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Abstract—**Knowledge of signal processing is very important for medical students. A medical signal may be used for monitoring, constructing an image, or for extracting the numerical quantity of a parameter. This information forms a basis for medical decisions. However, the processing of the signal may lead to distortion and an incorrect interpretation. The present article describes an educational practical for first year medical students. It uses the electrocardiogram, which can be obtained easily, as a convenient example of a medical signal. The practical was developed at the VU University Amsterdam and summarizes the elementary concepts of signal processing.**

Keywords—**Biomedical physics education, signal processing, practical, healthcare profession.**

I. Introduction

Much of the information about the health condition of a patient, presented to physicians and other healthcare workers, is obtained in the form of an electronic signal. This is true, even if the final form of presentation is an image or a parameter in a numeric form. A physical quantity, e.g. pressure, temperature, voltage, concentration, intensity of radiation, etc., is measured by means of a sensor or transducer and processed in the form of an analog electrical signal. This signal is always filtered in frequency content by the electronic equipment, fed into an analog-to-digital converter and converted at a specific sample rate and with a specific quantization. This conversion limits the temporal (or spatial in the case of an image) and amplitude resolution. The awareness that a biomedical signal has been processed and may have been distorted before presentation or parameter extraction is not self-evident to medical students. It is vital that the student in any healthcare education program receives explicit training in signal processing in order to be able to judge the validity of the presented information. Thus far, almost no activities in the field of teaching biomedical physics to healthcare professions have been published [1]. The present article describes an educational practical for first year medical students and summarizes the elementary concepts [2] in signal processing that are dealt with. The practical uses the electrocardiogram of the participating students as an example of a medical signal.

II. Registration of the ECG (Electrocardiogram)

The electrocardiogram is a signal, originating from the electrical activity of the muscles of the heart, which can be measured easily at the surface of the human body. Most of the first year students in healthcare educations are familiar with the existence of the signal and will recognize it from their text books as well as from popular presentations at television or in magazines. The signal is present in every student and can be obtained easily by placing two or three ECG-electrodes on the thorax or by putting clamps on the wrists and ankles. The underlying physiology and physics is elementary knowledge in first year medical education. The registration of the ECG and the connection of the cables to a pre-amplifier, an analog filter unit, an amplifier, an AD-converter and a subsequent computer will teach the students to construct a simple measurement chain.

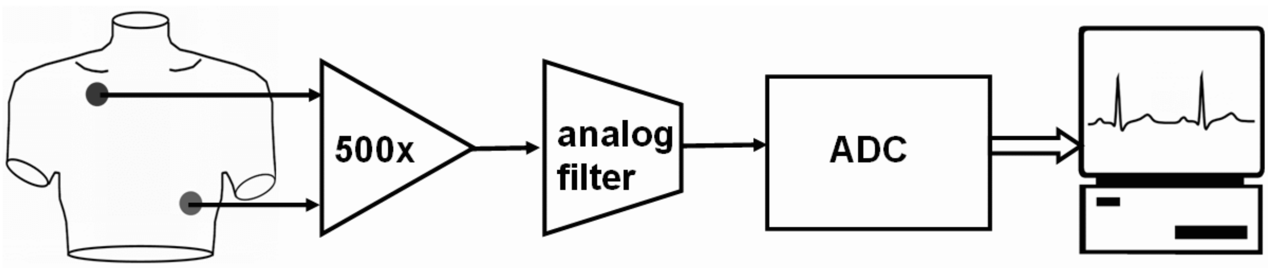

Fig. 1 The measurement chain consisting of electrodes, amplifier, filter, AD-converter and personal computer

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III. CONCEPTS OF SIGNAL PROCESSING

The practical consists of two parts. In the first part the students are requested to record the ECG-signal at each other and to introduce specific disturbances such as muscle noise and 50 Hz mains interference. The students operate in groups of two, of whom one is being measured and the other is making the recordings. In the second part, specific properties of the recorded signal are studied. During the practical, the students have to fill in a form with questions about the assignments in order to get their proper attention. The following concepts are considered to be relevant and are incorporated in the practical.

Fig. 2 ECG signal with 50 Hz noise

Measurement chain: A system consisting of more than one piece of equipment connected by wiring and meant to propagate and process a measurement signal is called a measurement chain (see Figure 1). The student is requested to construct a proper and functioning chain in order to understand the different steps in obtaining and processing a signal. Typically, the chain starts with a *sensor* or *transducer*, which senses the physical quantity and produces an electrical voltage that is proportional to the original quantity. This voltage signal is fed into one or more *amplifiers* and an *analog filter*, which makes the student aware that every piece of electronic equipment has its frequency limitations. Next, the signal is fed into an *AD-converter*, of which the specifications are discussed later in the practical, and stored on a *personal computer*.

Signal-to-noise ratio is one of the most important concepts in measurement theory in general and in signal processing in particular. At the start, the students are requested to make an ECG-recording without distortion. Then the students are requested to imagine factors that increase the amplitude of the signal and factors that produce noise. Next, the student who is being measured, is requested to bend the muscles of the chest and upper arms (like a body builder). The *muscle noise*, consequently appearing in the ECG-signal on the computer monitor, can be observed as a function of the tonus produced. The next assignment is to grab a power cable of the equipment. This will introduce a strong buzz with a frequency of 50 Hz (see Figure 2). This registration is stored on the hard disk of the computer in order to estimate the *signal-to noise ratio* later during the practical.

The next assignment is to breathe deeply using the diaphragm only and to keep the thorax as steady as possible. Two alterations of the ECG signal can be observed. During the breathing-in phase, noise from the diaphragm appears as an *amplitude modulation* (see Figure 3). During breathing-in, the diaphragm bends and produces *muscle noise*. During the breathing-out phase, the diaphragm relaxes and the noise disappears as the diaphragm moves passively back to the original position. Another disturbance that appears is the *frequency modulation* of the heart rhythm which originates from the cyclic negative pressure occurring inside the thorax as a consequence of the breathing activity. This phenomenon is called respiratory sinus-arrhythmia. It is caused by activity of the central nervous system, which regulates the blood pressure in response to pressure fluctuations inside the thorax and may disappear in patients with severe neuropathy. The amplitudes of the R-waves also show *amplitude modulation* caused by breathing.

Analog-to-digital conversion. The second part of the practical consists of the retrospective analysis of the processing of the stored ECG-signals. The original *sample frequency* of 1000 Hz can be reduced by the software. By sampling down in steps of a factor two, distortion grows and minimal sample frequency required for this ECG-signal

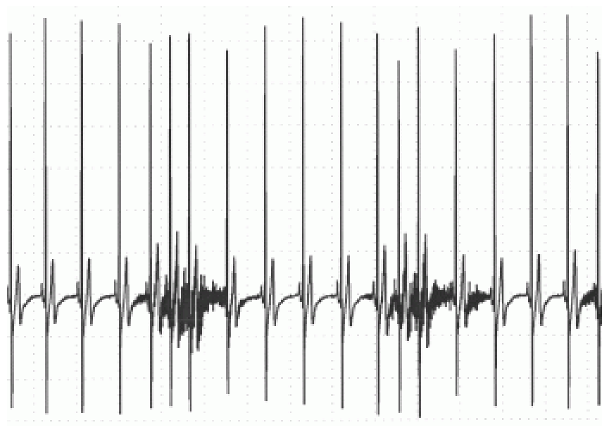

Fig. 3 ECG signal with cyclic muscle noise from the diaphragm and respiratory sinus-arrhythmia

can be estimated. By comparison with two other pre-recorded signals with a different frequency content (a bio-impedance breathing and a blood pressure signal) the difference in required sample frequency for different signals can be studied. A similar educational target can be reached by lowering the *quantization level* by the software to as low as 4, 3 or even 2 bits. This procedure will show that the amplitude of the signal consists of a number of steps, which limits the accurate representation of the signal. Both operations clearly demonstrate the *digital* nature of the signal, stored on the computer. By determining the RR-interval from the original ECG-signal and plotting it against time the concept of *parameter extraction* can be illustrated. This parameter extraction can be repeated after the deliberate distortion of the signals by lowering the sample frequency or quantization level or by filtering. This will reveal the influence of distortion on the determination of the numeric value of the parameter.

It is crucial for the students to have knowledge of *filtering*. The most common *high pass* and *low pass* filters can be applied at the stored ECG-signals and demonstrates the effects of filtering on the *frequency content*. The *order* of the filter is mentioned. The effect of *band pass* and *band stop* filters is conveniently demonstrated using the ECG-recording with the 50 Hz noise. The amplitude of the noise and the amplitude of R-waves can be measured easily from this recording. This provides the opportunity to determine quantitatively the effect of several filters on both signal as well as noise, and therefore on the *signal-to-noise ratio*. The practical ends with the message that, although filtering can enhance the signal-to-noise ratio substantially, there always will be a distortion of the original signal. It is the best ambition to obtain a signal that is as large as possible in the first place. The students are requested to imagine factors which will enlarge the signal (in this case: cleaning the skin with alcohol and sandpaper) and factors which will reduce the noise level (e.g., by letting the subject sitting or lying at ease).

IV. Closing remarks

This practical was developed and implemented in the medical curriculum at the medical school of the VU University. The size of the cohorts of the first year at this medical school is 360 students. Each practical consists of 24 students. The students operate in groups of two, of whom one is being measured and the other is making the recordings. The total duration of the practical is about two hours. The students can be motivated extra by pointing at the similarity between medical signal processing and music processing onto, e.g., a CD.

References

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