MEDICAL SIGNAL PROCESSING METHODS, BASED ON HARDWARE AND SOFTWARE IMPLEMENTATION OF MATHEMATICAL AND ENGINEERING ALGORITHMS

- Summary -

The concept of Professor in a University is a complex and highly dynamic one. This would imply on one hand the scientific competence validated by scientific studies, or the need of endless professionalization; on the other hand, there can be no idea of professor without the teaching vocation, that creates emulation among students, being ready to sacrifice on behalf of satisfaction hard to quantify and noticeable only on long term.

Thus, developing a strong research base in medical engineering, having as support the didactic foundation of electrical engineering, is a matter of great relevance in the contemporary society. And this could be achieved primarily through human and professional experience of those involved in this field.

For the purpose of the ideas set out above, **the first chapter** of the thesis acts as a preamble and presents the development of the candidate since the accession in the University, in 2000, and until now: the steps followed in the academic hierarchy, the professional and economic experience in the medical industry environment, internships conducted at Universities in Romania or abroad, or outstanding scientific results.

The second chapter presents methods for investigating signals from the heart. In most cases, addressing the heart rhythm variability targets heart rate calculation (HRV - Heart Rate Variability), that is the intervals between two consecutive R-R peaks. The method used in our studies imply using Hilbert transform in analyzing aspects of periodicity of the ECG signal; thus, for the healthy signals, the obtained vectorcardiogram needs to trace with high accuracy and rhythmicity a well delimited trajectory in two-dimensional plane. This method was applied to a test signal, simulated by a set of mathematical equations, but also on real signals, with or without cardiac pathologies, yielding consistent results: for the real ECG signals with sinus rhythm, it can be noticed the same trend as for the ideal (simulated) signal, namely that the vectorcardiogram tends to a limit cycle (instead, a real signal with heart pathology, no longer presents any regularity character, its vectorcardiogram no longer following a well-defined path in the two dimension plane).

Then, there are cases where some information from a signal cannot be observed fully in the time domain, but in the frequency domain only. Therefore, the use of the Fourier transform facilitates – through the energy and power distribution of the signal in the frequency domain, but also by analyzing its phase - a better analysis and description of signal characteristics. Due to the non-stationary nature of the ECG signal, a rigorous analysis can be performed using the STFT algorithm (a Hamming window in 512 points was chosen). Thus, 23 “*ante finem*” ECG holter recordings were analyzed, for patients with various heart diseases and various medical backgrounds; the data were then processed in Matlab, finally obtaining the spectrogram and the phase diagram of the signal. In this way, the importance of phase analysis of ECG signal was highlighted, as a complement to the time domain signal analysis and spectrogram. If in the time domain certain morphological or period changes of the signal can be determined, the

investigation becomes more complex when studying the spectrogram, which reveals only changes with high energy content within the signal (events materialized in waveforms with large amplitudes). Therefore, the phase signal analysis provides useful information on events with low energy content (evidenced in successive changes of the phase), which are not detectable neither in the time domain signal, nor on the spectrogram.

Another issue discussed in chapter two targeted the types of interference contaminating the ECG signals and how they can best be rejected. From this point of view, two cases were considered:

- *Technical interferences in the ECG signal*

In this regard, a real ECG signal, acquired using an ECG holter, was considered; during the acquisition process, the signal was contaminated with white noise. Since white noise is an infinite bandwidth noise, the proposed solution for optimal removal of the interference consist in a double filtering. First, a mean average filter (a 7 taps low-pass FIR filter, characterized by a linear phase), was designed; the result of this preliminary filtering has undergone a Butterworth filtering, by using a predefined LabVIEW filter (a 6^{th} order band-pass configuration IIR filter). Then, to the resulting signal, the Pan-Tompkins algorithm was applied, which is a specific R peak detection algorithm, that includes several stages of signal processing: filtering, differentiation, squaring, moving average integrator filter and finally, establishing adaptive threshold values (in the decisional stage). Also, the benefits of Pan-Tompkins algorithm for detecting the R peak were highlighted, in comparison with the simple method, based only on a threshold value.

- *Physiological interferences in the ECG signal*

A case of special complexity is represented by the interference of maternal and fetal ECG. Consequently, a filtering algorithm for the maternal ECG it was implemented, which is very useful in fetal electrocardiography; as starting point, mathematically synthesized signals and noises from the MIT-BIH database were considered, with various signal/noise ratios.

As initial parameters of the simulated scenario, the maternal ECG amplitude was considered twice greater than the fetal one and the fetal heart frequency twice higher than the maternal one. Although in real situations these ratios have other values, in this case they were preferred for practical reasons (simplification of the model). In order to perform the separation of the two signals, adaptive filtering was used, by implementing the “Convex Variable Step Size” algorithm - a modified version of the “Least Mean Square Algorithm”. The results show that the two electrocardiograms (maternal and fetal) were identified and separated successfully.

The last part of the chapter dealt with the issue of determining the heart rate, by involving no physical contact with the patient. This approach presents advantages in situations where the subject is the victim of a fire (severe burns on the body), an avalanche or earthquake, or if the measurement targets military applications (discovering hidden enemy combatants behind walls or assessing the combatants’ status on the battlefield).

Achieving this objective has as starting point processing and analyzing algorithms of the shifting phase of the received signal of a Doppler continuous wave radar system. Such a radar system will send an unmodulated carrier and receives the reflected signal, which is phase modulated.

The permanent movement of the human body, due to the heart-beat and breathing, will produce a phase modulation of the reflected signal; in consequence, the reception module of the radar system will evaluate the respiratory rhythm and the heart rate of the subject, based on the estimation of the phase modulation parameters.

The research has focused on the high accuracy detection of heart rate, for very short measuring periods and for a low signal/noise ratio, by implementing in Matlab a parametric spectral estimation algorithm (MUSIC - MUltiple SIgnal Classification) and a FFT non-parametric spectral estimation algorithm. The validation of the results was performed by using a reference system, i.e. the VERNIER laboratory kit, which performs measurement of the heart rate by direct contact with the subject under investigation.

The results obtained highlighted MUSIC algorithm's ability to separate the useful signal from noise and the correct identification of cardiac rhythm, unlike the FFT algorithm which has difficulties when evaluating this vital parameter, especially for small segments of signal measurements. In addition, a statistical analysis of the obtained results points the fact that for 66% of measurements, MUSIC algorithm estimates the heartbeat with an error less than 10 beats/minute, while the FFT algorithm can provide the same performance for only 23% of the carried out measurements.

Further studies will aim testing the MUSIC algorithm in different environments (snow, water) and in the presence of various obstacles (walls of different thicknesses and materials), but also for a great number of subjects.

The material included in **chapter three** studies the relationship between EMG signal and temperature, during the effort. The experiments performed aimed studying the behavior of forearm muscles during isotonic exercise, for different loads, in terms of electrical perspective (EMG signal) and temperature (global warming evaluation of the studied area).

During the experiments, the subject has undergone successive tests, with right hand on a fixed support, arm and forearm by an angle of 90°. The effort was simulated with the help of a hand dynamometer, that the subject would gradually squeezed with varying force (50 N, 100 N, 150 N, 200 N), and having the sensors for the EMG recording placed on the arm, in the aria of the radial muscle. The infrared camera that picks the temperature signal has been placed in a fixed position, at a distance of 50 cm. above the investigated forearm (that of the right hand, the subject investigated being a right handed).

As a result of Matlab processing of the experimental data, it was found the fact that the force-EMG characteristic linearity is allowed only for small loads (50 N, 100 N, 150 N); continuing the experiment with higher values of force (200 N) imply the loss of linearity, the characteristic rising sharply at high values of the EMG amplitude. Also, as the stress increases, the muscles fatigues rapidly (EMG amplitudes increase) and the temperature, after increasing relatively linear over the stress, tends to stabilize to a certain value (fact that is highlighted by the force-temperature characteristic).

The measurement of thermal distribution was also studied for the facial area, during mastication. During these experiments, it was observed the way that EMG and thermal field vary, for food of different consistencies. The electrodes for EMG recording were placed on the face, in the area of the active muscles, and in terms of heat, it was considered a rectangular area of interest (which includes ramifications of the facial artery), for which the average and maximum temperature were monitored.

The proposed subject highlights the correlation between the level of stress (effort) that confronts the muscle and its electrical response (EMG signal), together with the qualitative and quantitative evaluation of thermal changes observed in the investigated area.

As a result of the blood supply that heats the investigated area, this approach also emphasizes the trajectories of blood vessels, which are close to the skin surface. In this case, as the muscles effort increases, on the thermal map of the forearm the brachial artery and its ramifications are visible; for the second experiment, on the thermal map of the face, the areas crossed by the facial artery are visible.

The research can be extended in the future on people of both sexes and different physical configurations (height, weight), covering different physical activities (athletes, people with muscular dystrophies or in period of rehabilitation, post-traumatic), in order to compare the results and establish causal-effect relationships.

Chapter four discusses the ECG signal transfer possibilities, having as starting point a hierarchy, in terms of distance. Thus, the proximal transfer was performed by using the Fast Infrared technology (FIR), in a client-server type architecture, implemented in LabVIEW. The same architecture (client-server) was also created for the short range ECG signal transfer, on a mobile phone, via Bluetooth technology (Bt).

As medical data should be disseminated to the whole international community of experts, developing techniques for long range transmission are required. The proposed solution is to create a flexible (with three access levels - administrator, physician and patient) and low cost system for monitoring and transmitting medical data, which contains terminals (server, client) and implies (besides the acquired ECG signal) knowledge of Java, PHP, MYSQL, HTML.

The concerns in the field of rehabilitation, discussed in **chapter five**, have considered creating a wireless monitoring system of the leg's load, by measuring the downforce at the level of the sole. This approach targeted to avoid excessive loading of the foot, for patients who are in a process of post-traumatic recovery. Thus, the system allows the patient to begin a controlled treatment of the leg's load, during rehabilitation in a hospital or at home.

The plantar pressure is measured in a three chamber flexible network, placed under three anatomic areas of maximum load of the sole; the measurement process uses a pressure sensor, and the obtained value is converted into a force value.

In this way, monitoring the maximum downforce on the leg's sole uses only one pressure transducer; the obtained information is converted into a force value, based on a calibration algorithm implemented on a microcontroller, and the communication of the measured values to a physician is achieved via a radio interface. There is also the possibility of alerting the patient by sound and light signals, if the preset (by the physician) force threshold values, stored in the measuring block, are exceeded.

For the proposed system to be accessible, the idea was based on the following concepts: the system must be compact and low cost. All information obtained during treatment can be used by the physician in assessing the patient's progress, during the chosen period of time.

Thus, it enables the specialist to verify both the compliance with recommendations, but also to adjust the treatment in a way that best suits the specific evolution of each patient.

Then, another direction discussed in this chapter has focused on implementing an efficient method of communication (as an alternative to the use of language, hand gesturing or head movements), that would improve life quality of the people with severe disabilities (paralysis and paraplegia).

Controlling interfaces by using the eyeball movements have their origin in applications that have been implemented in the military area, but also in the video games industry. In this case, the recorded EOG signal was used to control a graphical interface that would allow the subject to express the pain, emotional state, to switch the TV channel or to write a text.

The algorithm that controls this application classifies eye movements for each channel (horizontal and vertical), and voluntary eye blinks decide the moment when a certain button on the graphical interface will be activated.

The dynamics of exact sciences, in which always new technologies and algorithms emerge, provides a solid potential for investigation and efforts made for supporting and improving the quality of life and the medical approach. Consequently, **chapter six** discusses future research directions concerning aspects of the human body.

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