MODULAR SYSTEM FOR ASSESSMENT OF THE THYROID GLAND FUNCTIONAL STATE - BIOLAB

V. Rosík*, P. Kneppo**, M. Tyšler*, J. Ždiňák*, J. Švehlíková*

* Institution of Measurement Science, Slovak Academy of Sciences, Bratislava, Slovakia
** Faculty of Biomedical Engineering, Czech Technical University in Prague, Czech Republic

umerrosi@savba.sk

Abstract: Distributed modular system BioLab for biophysical examinations enabling assessment of the thyroid gland functional state is presented in the paper. The BioLab system is based on a standard notebook or desktop PC connected to an Ethernet-based network of several smart sensors. These sensors are programmed and controlled from PC and enable measurement and evaluation of selected biosignals. Two sensors for assessment of parameters of the human cardiovascular and neuromuscular system that are influenced by the production of thyroid gland hormones are introduced. Using these sensors, ECG, PCG and CTG signals are recorded to compute systolic time intervals and Achilles tendon reflex signal is recorded to compute the half relaxation time. These intervals serve as peripheral indicators characterizing the thyroid gland functional state and are used to estimate the total level of the thyroxine T4 thyroid gland hormone.

Introduction

Development of a measuring system using Ethernet as a communication interface between a few smart sensors and a controlling PC offers the possibility to build local area or even wide area configurations of modular systems for various biomedical applications. They allow immediate acquiring of different of medical information that was previously obtained off-line or by several independent measuring devices. In this way the networked solution saves time and costs in medical facilities and improves the quality of medical care.

Based on previous experience with the diagnostic method [1], the aim of the presented work was to develop hardware and software components of a modular networked measuring system for laboratory biophysical examinations allowing to assess patient's thyroid gland functional state using peripheral indicators of his/her cardiovascular and neuromuscular systems [2]. In comparison with other, mainly biochemical methods, such examinations are non-traumatizing and in most cases provide enough diagnostic information at much lower costs.

Method and Materials

Evaluation of the dynamics of the neuromuscular and cardiovascular system that are influenced by the production of thyroid gland hormones is used to assess the functional state of the thyroid gland.

Increased production of thyroid gland hormones induces faster actions of the neuromuscular system and vice versa. Based on this relation, dynamics of Achilles tendon reflex (ATR) is evaluated as one of peripheral indicators of thyroid gland function and its time intervals are evaluated as shown in Figure 1:

- ATR contraction time – TK [s],
- ATR half-relaxation time – TH [s]
- ATR relaxation time – TR [s]

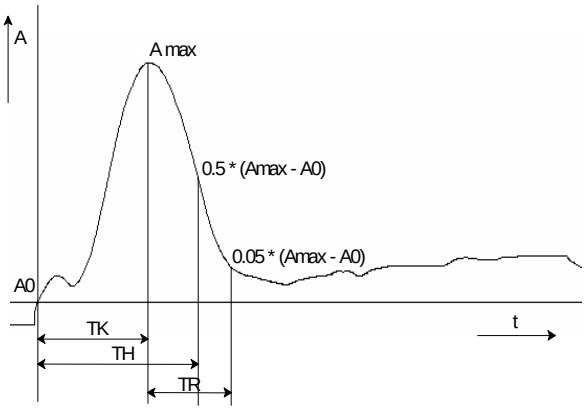

Figure 1: Evaluation of the contraction time TK, half relaxation time TH and relaxation time TR from the measured ATR signal

By default, the TH interval from 6 correct measurements is considered, maximal and minimal values are excluded and TH average from remaining values, corrected for patient's height and sex using the formulas:

for men: THc = TH * (175/ patient height [cm])
for women: THc = TH * (165/ patient height [cm])

is used for further diagnostic evaluation.

Similarly, three parameters characterizing the dynamics of the cardiovascular system are evaluated:

- Pre-ejection period of the heart systole – PEP [s],
- Electromechanical systole – QS2 [s],
- Heart rate – HR [bpm].

To obtain these parameters - systolic time intervals (STI) - three signals are recorded and evaluated as shown in Figure 2: Electrocardiogram (ECG) is used to find the Q-wave onset Q and R-R interval, phonocardiogram (PCG) serves to find the second

ISSN: 1727-1983

reverberation time instant S2 and carotidogram (CTG) is used to find the upstroke and incisure in the signal.

To obtain the pre-ejection period PEP, time interval of the electro-mechanic systole QS2 and ejection time of the left ventricle LVET is estimated first. Duration of the PEP is then obtained as PEP = QS2 –LVET. Finally, heart rate is estimated from the mean time interval R-R, i.e. the interval between consecutive QRS complexes in the ECG signal.

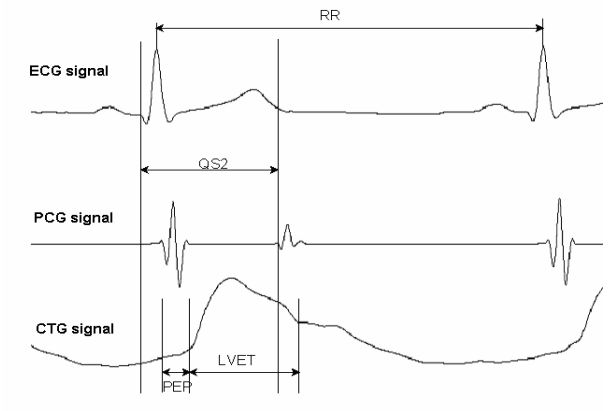

Figure 2: Evaluation of the pre-ejection phase interval PEP using the ECG signal (top tracing), phonocardiogram (tracing in the middle) and carotidogram (bottom tracing)

Optionally, obtained STI are corrected for the heart rate HR according to Weissler and STI corrected values QS2i, LVETi, PEPi are used for diagnostic evaluation:

QS2i (men): QS2 + [(2.1 * HR) x 0.001]
QS2i (women): QS2 + [(2.0 * HR) x 0.001]
LVETi (men): LVET + [(1.7 * HR) * 0.001]
LVETi (women): LVET + [(1.6 * HR) * 0.001]
PEPi (men): PEP + [(0.4 * HR) * 0.001]
PEPi (women): PEP + [(0.4 * HR) * 0.001]

Finally, the total Thyroxine T4 level [nmol/l] based on the above biophysical measurements of peripheral indicators can be estimated using some of the following regression equations [3]:

ln T4 = 9.0233 – 7.76 TH – 8.326 PEP – 1.011 RR
ln T4 = 7.4102 – 10.39 TH + 7.246 QS2 – 2.47 RR
ln T4 = 8.9013 – 8.817 TH – 11.734 PEP
ln T4 = 8.8840 – 9.245 TH – 1.307 RR
ln T4 = 8.7449 – 11.4 TH – 0.5 QS2
ln T4 = 8.62104 – 11.69 TH
ln T4 = 8.57244 – 22.43 PEP – 1.8825 RR
ln T4 = 8.1857 – 33.67 PEP
ln T4 = 7.8443 – 0.7629 QS2 – 3.572 RR
ln T4 = 7.6733 – 3.726 RR
ln T4 = 9.9319 – 13.76 QS2

Several equations using desired combination of available peripheral parameters can be used, however, generally the more parameters are used in the equation, the higher is the reliability of the estimate. The equations are displayed with descending reliability of the estimate.

Results of all available examinations together with the estimated T4 level can be presented in numerical form or in well-arranged circular diagram as shown in Figure 3. Values of all evaluated peripheral parameters and overall thyroxin T4 level are displayed relatively to a normal range (area between the circles in Figure3).

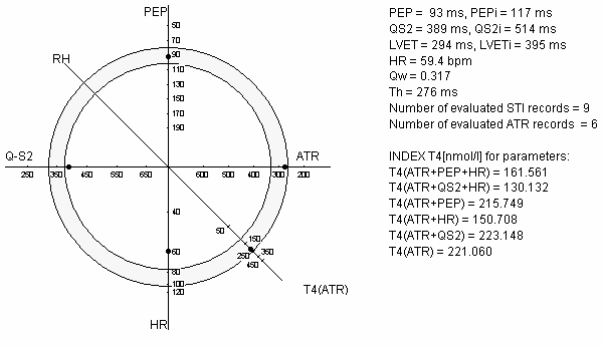

Figure 3: STI and ATR evaluation and estimated T4 hormone level displayed in a circular diagram.

The above described method was implemented in the BioLab distributed modular measuring system for biophysical examinations that consists of a set of smart sensors and a controlling PC. All these components are connected to the Ethernet network. In principle, configuration of the system can be local or distributed depending on the requirements of the user.

Core of each BioLab smart sensor module (Figure 4) is Analog Devices ADμC812 microcontroller chip with a measuring unit and interface control completed with a RS 232C to TCP/IP converter with RJ45 Ethernet connector enabling connection of the module to a data processing PC via the Ethernet network. For the patient safety, module is optically isolated from the Ethernet and is powered by Li-Ion battery enabling approximately 6 hours of measurement. Due to advanced power management, average battery operating time is about 5 working days, however, device can be operated also during the battery charging from an isolated charger.

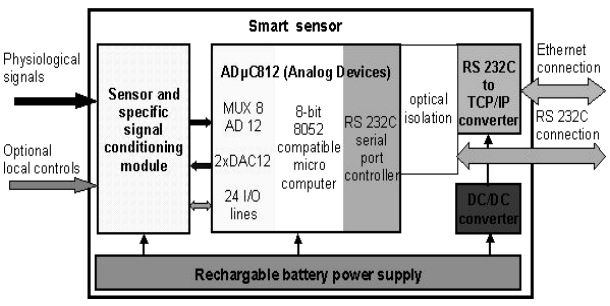

Figure 4: Simplified block scheme of the BioLab smart sensor module

ISSN: 1727-1983

Two smart sensors were developed for noninvasive assessment of the functional state of human thyroid gland: BioLab ATR sensor for Achilles tendon reflex measurement and BioLab STI sensor for measurement of systolic time intervals. Both sensors are based on the previously presented concept [2] of a network-based modular measuring system.

BioLab ATR smart sensor. This sensor is shown in Figure 5 and enables noninvasive revealing of the effect of thyroid gland hormones on the neuromuscular system.

Figure 5: BioLab ATR smart sensor module with optoelectronic sole movement sensor and synchronized stimulating neurologic hammer.

Time intervals of the Achilles tendon reflex are measured by a non-contact, optoelectronic device sensing the movement of the sole (Figure 6). The reflex is initiated by a neurological hammer and the tendon jerk causes motion of the sole that is scanned by an IR optoelectronic system as the ATR signal. Input module of the sensor contains three infra-red emitting diodes and a photo-transistor sensing the radiation reflected by the moving sole. Switching of the emitting diodes and sampling of the photo detector output is controlled directly by the ADμC812 chip of the smart sensor. Intensity of the reflected radiation depends on the distance between the sensor and the sole. Recorded ATR signal is electronically synchronized with the time instant of the stimulus, sampled with 1 kHz rate and sent over the Ethernet to the processing PC.

BioLab STI smart sensor. BioLab STI (Figure 7) is a 3-channel sensor developed to obtain information on cardiovascular dynamics influenced by thyroid gland hormones. It enables measurement of one electrocardiographic lead (ECG, mostly standard lead II), phonocardiogram (PCG, frequency band 1) and carotidogram - signal of the carotid pulse wave (CTG).

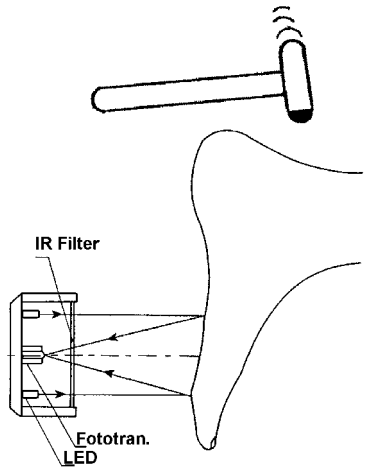

Figure 6: Principle of the ATR signal measurement.

Figure 6: BioLab STI smart sensor module with ECG electrodes, cardio microphone and piezzo-electric sensor of the carotid pulse wave.

ECG signal is sensed by a set of 3 disposable Ag-AgCl electrodes, programmable gain of the ECG channel is from 0 to 10200 and frequency range is 0.16 Hz – 1 kHz. Active patient neutralization is used to improve common-mode signal rejection ratio (Figure 8).

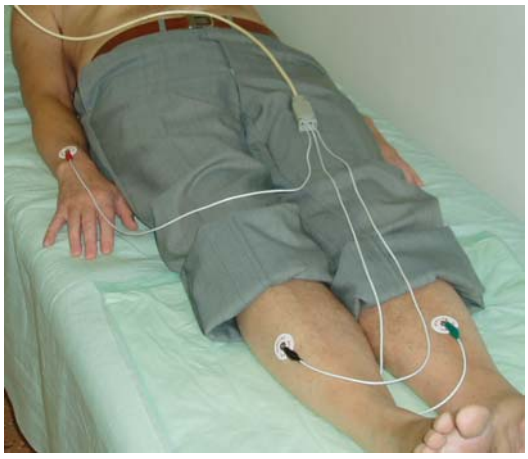

Figure 8: ECG measurement using three disposable Ag-AgCl electrodes

ISSN: 1727-1983

ADInstruments MLT 201 Cardio Microphone is used for recording of the PCG heart sounds (Figure 9). PCG signal is amplified with programmable gain from 0 to 10000 and is processed in a band-pass filter with frequency f = 35 Hz and symmetric band attenuation B = -12 dB/octave (band F1 by Maase – Weber).

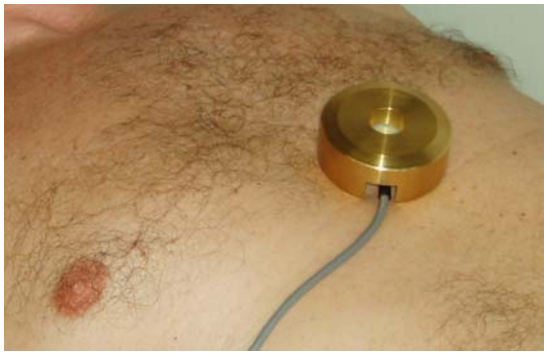

Figure 9: PCG measurement using the ADInstruments MLT 201 Cardio Microphone

ADInstruments MLT 1010 piezzo-electric transducer is used for converting carotid pulse wave signal CTG into an electrical signal (Figure 10). CTG channel has also programmable gain from 0 to 450 and frequency range 0.16 Hz – 1 kHz.

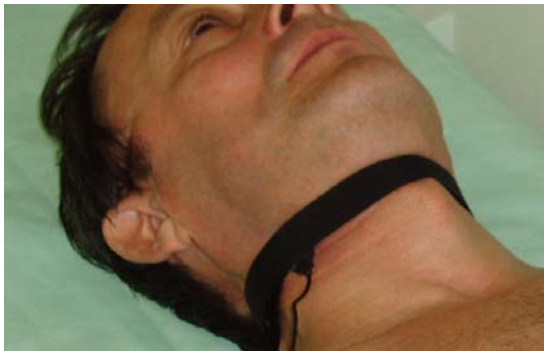

Figure 10: CTG measurement using the ADInstruments MLT 1010 piezzo-electric transducer

For patient safety, there is an optical isolation in all channels that is placed between the signal preamplifier and the programmable amplifier. After proper amplification, all three signals are sampled by the ADμC812 chip with 1 kHz (or 500 Hz) rate. Microcomputer also provides optimal gain setting in all channels. Sampled data are sent over the Ethernet network to the PC where they are evaluated.

BioLab application software is a 32-bit application running under Windows XP operating system and developed in MS Visual C++ and Microsoft Foundation Class library with graphical user interface. It allows full control of the connected smart sensors and enables real-time monitoring of measured biosignals, their visualization on computer display and recording. Comfortable and easy to use measuring program includes resources for adjustment of all sensors parameters, such as sampling period, gain of amplifiers or Ethernet communication parameters.

Communication between smart sensors and controlling PC is over the Ethernet network and is based on a client-server model and TCP/IP network protocol. Smart sensors present servers and PC is connected as a client when needed. Only one single PC can be simultaneously connected to each smart sensor.

Recorded biosignals are automatically processed to obtain parameters needed for evaluation of patient's thyroid gland functional state using the method described above. Results of the classification are displayed in a circular diagram as shown in Figure 3.

Results

Presented system, has been successfully used in the clinic for routine screening of thyroid gland patients as well as a learning tool in courses of biomedical engineering. It combines simplicity of the measuring method with advanced technology to obtain reliable measurements.

In Figure 11 there is a snapshot of the computer screen during the examination of the neuromuscular system after the ATR time intervals were evaluated.

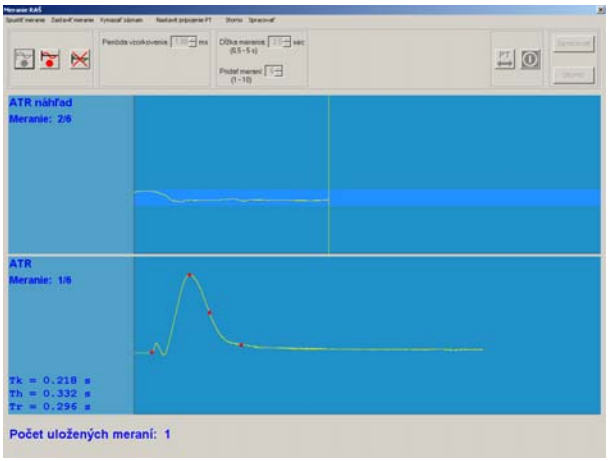

Figure 11: Screenshots of the evaluation of the ATR signal with marked time instants TK, TH and TR.

In Figure 12 there is a snapshot of the computer screen during the examination of the cardiovascular system, after the cardiovascular signals were processed and systolic time intervals were evaluated.

Discussion

Presented method and system were proposed for fast noninvasive screening tests enabling to assess the functional state of the thyroid gland. Future possible extensions of the system include measurement of radiating heat and blood pressure as additional peripheral indicators coming from the thermoregulatory and cardiovascular system. However, their inclusion in the regression equations for T4 estimation would need extensive experimental material.

ISSN: 1727-1983

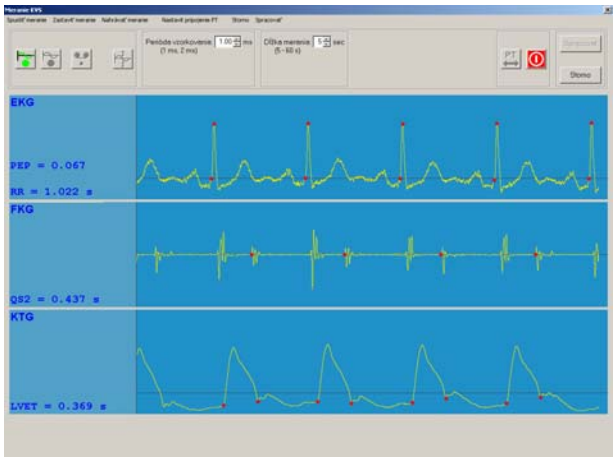

Figure 12: Screenshot of the evaluation of cardiovascular signals. Automatically detected time instants Q and R in the ECG signal, S2 in the PCG signal, upstroke and incisure in the CAR signal are marked in the recordings and used for computation of systolic time intervals.

For wider acceptance of the method in the clinical practice, estimation of another hormone levels recently used in biochemical analysis is desirable. This task is possible in cooperation with medical institutes and biophysical laboratories.

Conclusions

Presented system was proposed for fast noninvasive screening tests enabling to assess the functional state of the thyroid gland. From the users' point of view, another advantage of the system is it variability and possibility to extend it to other examinations. Modular concept of the system cuts the cost and time for its development and implementation and enables to adapt its configuration according to the user requirements. Possible future extension of the system depends on the response from the medical and biomedical engineering community.

Acknowledgement

This work was supported by grant 51-51-9014-00/2002 from the Slovak Academy of Sciences and grant APVT-51-017802 from the Grant Agency for Science and Technology.

References

[1] P. KNEPPO, E. KUŽMA, V. ORAVEC, V. ROSÍK (1989): 'THYREOMAT - mikropočítačový systém na hodnotenie funkčného stavu štítnej žľazy pomocou periférnych ukazovateľov' (in Slovak), *Physician & Technology journal (Lékař a technika)*, ***20***, pp. 97-104

[2] V. ROSÍK, M. TYŠLER, J. ŽDIŇÁK, R. RÁŠO (2003): 'Modular Measuring System for Biophysical Examination', *Proceedings of the 4th International Conference on Measurement,* Smolenice, Slovakia, 2003, pp. 242-245

[3] S. VÁŇA, R. REISENAUER, J. NĚMEC, J. BEDNÁŘ (1985): 'Index obvodového tyreoidálního účinku v jednotkách odpovídajících celkovému tyroxynu v séru' (in Czech), *Internal medicine (Vnitřní Lékařství),* ***31***, pp.474 – 481

ISSN: 1727-1983