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COMMUNICATIONS

APPLICATION OF ACCELERATION SENSORS IN PHYSIOLOGICAL EXPERIMENTS

Erik Vavrinský [*] — Daniela Moskaľová [**] — Martin Daříček [*] — Martin Donoval [*] — František Horínek [*] — Marián Popovič [*] — Peter Miklovič [***]

This paper illustrates a promising application of an accelerometer sensor in physiological research, we demonstrated use of accelerometers for monitoring the standard proband physical activity (PA) and also in special applications like respiration and mechanical heart activity, the so-called seismocardiography (SCG) monitoring, physiological activation monitoring and mechanomyography (MMG).

K e y w o r d s: acceleration sensor, physiology, heart activity, mechanomyography

1 INTRODUCTION

Additionally, to monitoring of typical physiological parameters by electromyography (EMG), electrocardiography (ECG), pulse-oximetry, and of derived parameters, such as respiration, heart rate variability (HRV), concentration of oxygen in blood *etc*, in all our proposed system we integrate a 3-dimensional accelerometer and magnetometer in order to measure and utilize the proband's (tested person) body movement and physical activity in further analyses. This is very useful in sport medicine, rehabilitation centres or neurological research, where we can monitor the total proband's activity, reaction times, body position, stability *etc*.

In literature there are several interesting and innovative bio-experiments that use separate accelerometers. In such a manner we have verified that the capability of integrated sensor is reliable in such experiments.

The dominant role of accelerometers in physiology is monitoring of physical activity (PA), which is one of the most important determinants of health. Wearable sensors have a great potential for accurate assessment of PA (activity type and Energy Expenditure (EE)) in daily life [1]. Especially in today's industrialized societies, the population's physical activity level is decreasing below the recommended levels. As a result, new epidemics (*eg*, obesity, diabetes) are spreading all over the world. New technologies seamlessly integrated in everyone's life, able to monitor the behaviour objectively and non-invasively, can provide unprecedented insights into the relations between PA and health [2]. Very well know are experiments focused on monitoring the obesity of children, where accelerometers provide an objective measure of habitual activity which is not dependent on self-report [3] or monitoring of elderly persons in the homecare, where the system provides an application for recording their activities, events and potentially important medical symptoms [4].

Another interesting area is mechanomyography (MMG) — monitoring of amyostasia, which are small vibrations of loaded muscles. MMG may provide a useful alternative to the electromyogram (EMG) for monitoring the muscular activity. It has a higher signal-to-noise ratio than surface EMG and thus can be used to monitor the activity of deeper muscles without using invasive measurement techniques. This technique is often used to monitor the proband's muscular fatigue [5, 6].

Another very interesting application is seismocardiography (SCG), which is the measurement of vibrations of the chest caused by the heartbeat, where SCG contains information related to both cardiovascular and respiratory systems. The chest-accelerometer signal contains an ultra-low frequency component corresponding to the motion of the chest wall and a higher frequency seismocardiogram (SCG) component corresponding to vibrations of the chest caused by the heartbeat. Some research works try to develop algorithms for extracting these signals [7] and some are focused on increasing the quality of real-time monitored ECG signal by quantitative analysis of motion artefacts [8].

2 SUBJECT AND METHODS

During experiments we used two types of biosensor systems both with a built-in accelerometer sensor. The Biosense v.4.0 comprises Freescale Xtrinsic MMA8451Q accelerometer from Freescale, while the ECG Holter v.1.0 is equipped by STM LIS3DH from ST Electronics.

[*] Institute of Electronics and Photonics, Slovak University of Technology, Ilkovičcova 3, 812 19 Bratislava, Slovakia; [**] Department of Psychology, Comenius University, Gondova 2, 814 99 Bratislava, Slovakia; [***]Technological Institute of Sports, Slovak University of Technology, Ilkovičova 3, 812 19 Bratislava, Slovakia, erik.vavrinsky@stuba.sk

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Xtrinsic MMA8451Q is a smart, low-power, 3-axes, capacitive, micro-machined accelerometer of 8 bit resolution with dynamically user selectable full scales of ±2g/ ± 4g/ ± 8g. This accelerometer is packed with embedded functions of flexible user programmable options, configurable to two interrupt pins. There is an access to both low-pass filtered data as well as high-pass filtered data, which minimizes the data analysis required for jolt detection and faster transitions [9]. The LIS3DH is an ultra low-power high performance three axes linear accelerometer belonging to the "nano" family. The device features ultra low-power operational modes that allow advanced power saving and smart embedded functions. The LIS3DH has a dynamic user selectable full scale of ±2g/ ± 4g/ ± 8g/ ± 16g and is capable of 16 bit output resolution [10]. Note, that here and elsewhere the units of measured acceleration (sometimes also called "g-force") are simply multiples of the gravitational constant $g = 9.81\ \mathrm{m/s^2}$.

Freescale MMA8451Q (Biosense)

- 8-bit digital output
- Dynamically selectable full-scale: ±2g/ ± 4g/ ± 8g
- Sampling rate: 1.56 to 800 Hz
- I2C digital output interface (operates to 2.25 MHz with 4.7 kΩ)
- Supply voltage: 1.95 V to 3.6 V
- Current Consumption: 6 to 165 μA
- Two programmable interrupt pins for seven interrupt sources

ST Electronics LIS3DH (ECG Holter)

- 16 bit data output
- Dynamically selectable full-scale: $\pm 2g/\pm 4g/\pm 8g/\pm 16g$
- Sampling rate: 1 Hz to 5 kHz
- I2C/SPI digital output interface
- Supply voltage: 1.71 V to 3.6 V
- Ultra low-power mode consumption 2 μA
- Two independent programmable interrupt generators for free-fall and motion detection

3 PHYSIOLOGICAL MONITORING EXPERIMENTS

The experiments were carried out on a sample of about 30 probands. The results described in this chapter briefly describe an example of using the innovative monitoring of physiological parameters by the presented units. In all experiments a dynamic full scale range $\pm 2g$ and sampling frequency 125 Hz were used.

Application of 8-bit accelerometer in mechanomyography respiration and heart activity monitoring

In the first experiment we monitored muscle fatigue of femoral and calf muscles using the Biosense system. Fatigue is ordinarily analysed from the changes in RMS (EMG_{RMS}) and median frequency (EMG_{MF}) of EMG signal, but according to additional references [5, 6, 11] a special method called mechanomyography (MMG) can be employed. MMG monitors amyostasia, which are small vibrations of loaded muscles. Signals displayed in Fig. 1 were recorded at 15 % MVC (maximum voluntary contraction) of isometric load, where the load was applied in five thirty-second series. In the result, see Tab. 1, there is an obvious increase in MMG_{RMS} amplitude of acceleration between each series, but also during a single series, which corresponds to EMG_{RMS} increase and EMG_{MF} decrease.

Table 1. MMG and EMG comparison

	Series 1 (Start)	Series 1 (End)	Series 5 (Start)	Series 5 (End)
MMG_{RMS} (mg)	12.4	12.8	19	22.9
EMG_{RMS} (mV)	51	62	80	100
EMG_{MF} (Hz)	75.9	72.2	66.1	64.6

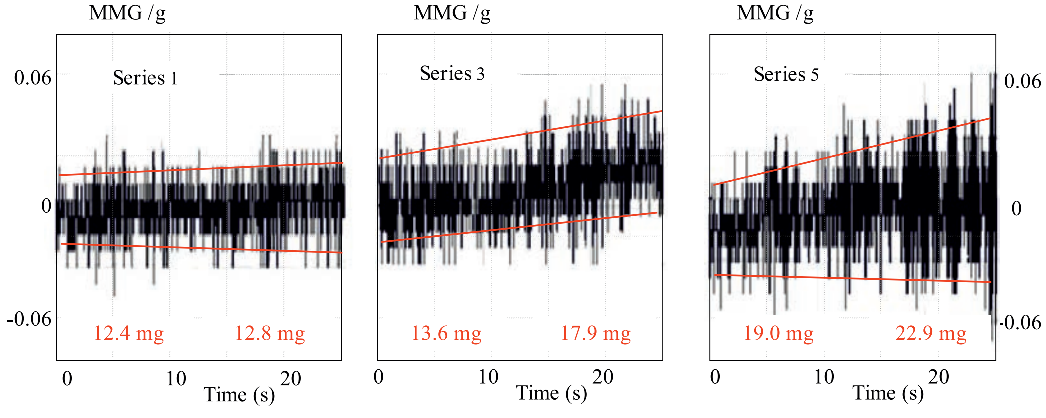

Fig. 1. Application of 8-bit accelerometer in mechanomyography

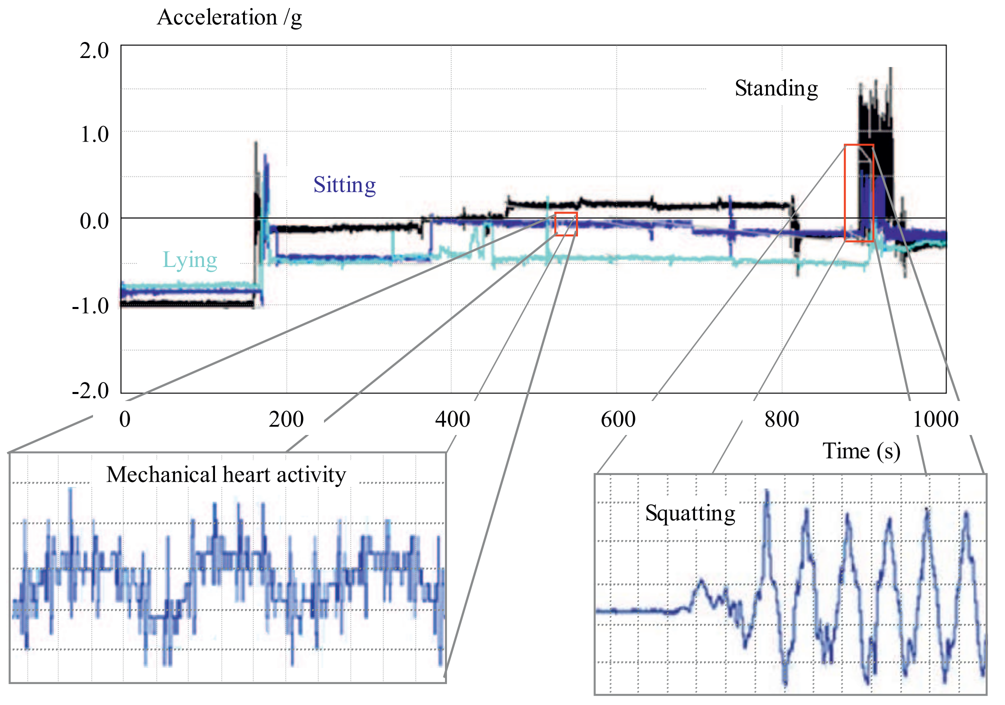

Fig. 2. Physiological monitoring: movement monitoring via 8-bit accelerometer (3 probands), zoom: Respiration and ECG activity

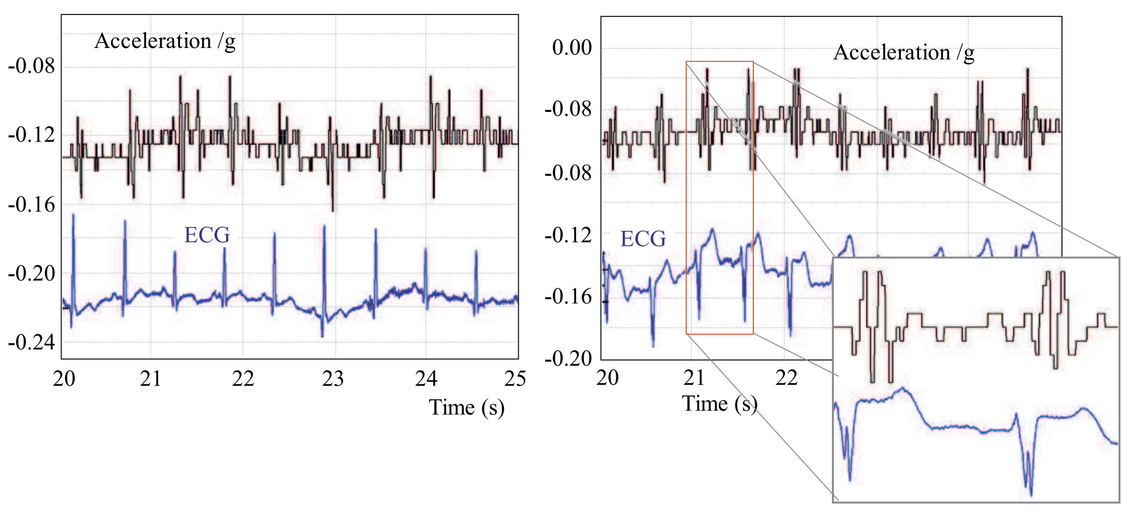

Fig. 3. Physiological monitoring: movement monitoring via 8-bit ccelerometer (3 probands): zoom: Respiration and ECG activity monitoring

Table 2. Time-shift between ECG and acceleration

Proband		Activity					
		Lying Relax	Sitting Relax	Sitting Test	Standing Relax	Standing Test	Standing Relax
MM3 male	HRV (min^{-1})	73.7	79	80	83.9	115.7	111.5
	Time shift (ms)	85	100	97	100	82	90
PL female	HRV (min^{-1})	61.9	81.8	74	86.3	114.2	79.2
	Time shift (ms)	60	70	65	65	60	65

In the following experiment we applied the Biosense system. The unit was fixed to the thorax using a simple chest belt, while the ECG was monitored. The experi-

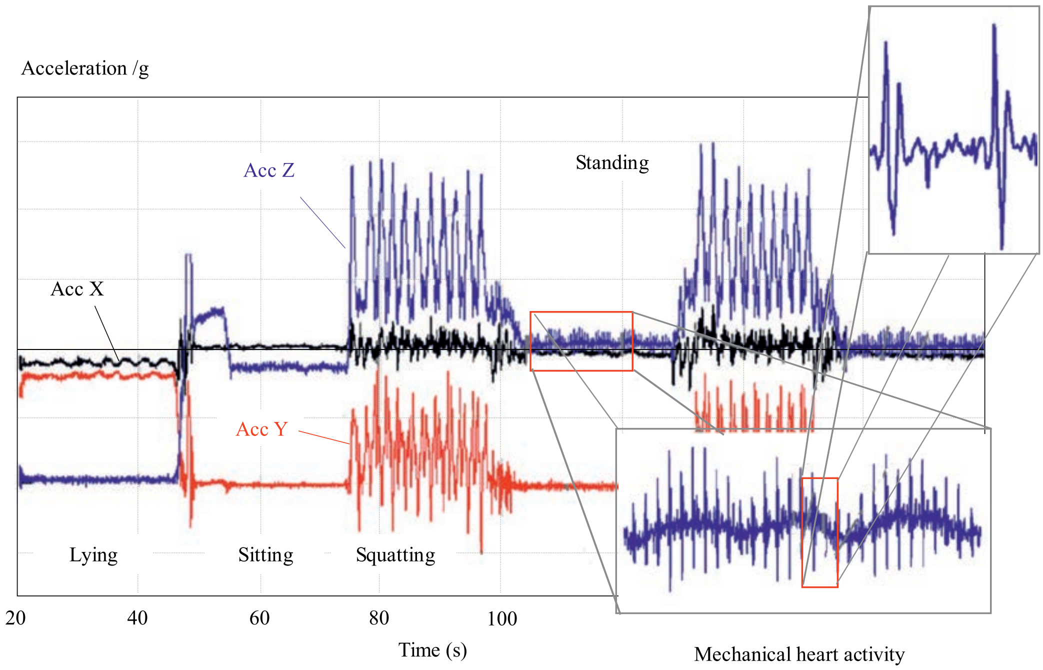

Fig. 4. Acceleration experiment with ECG Holter respiration and ECG activity monitoring

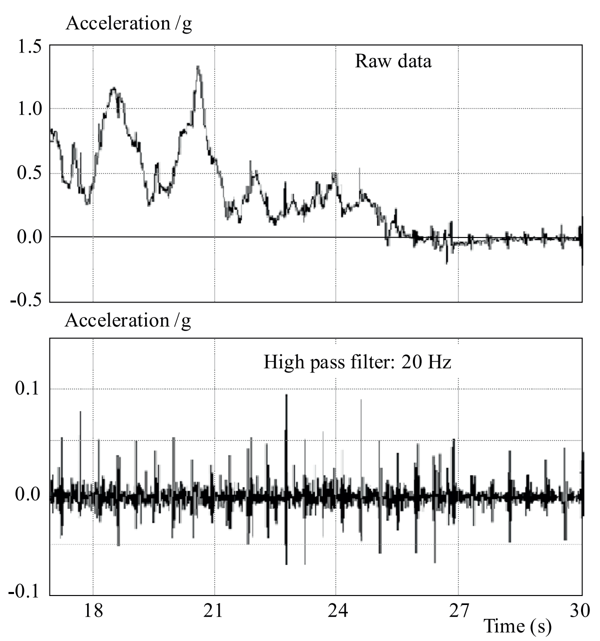

Fig. 5. HRV analysis during physical exercise

ment was primarily focused on EDR (ECG Derived Respiration) evaluation [12], where the built-in accelerometer showed other promising results. Fig. 2 illustrates acceleration measurements on the thorax during a 30 minute experiment in three probands. From the overall signal one can identify the body position and movement — physical activity. In more detail the acceleration signal corresponding to mechanical activity of heart, specifically breathing and heart beating can be observed — seismocardiography (SCG). Respiration corresponds to the slow sinuosity and ECG to fast pulses in the graph zoom. The comparison between measured ECG and acceleration signal (Fig. 3) brought other promising results. Since the signal shapes look similar, a relation was found and observed between the time-shift of these signals and physical or mental activity of the probands (Fig. 3 and Tab. 2). All these results seem to be very promising for the future research but suffer from a low resolution of the used 8-bit accelerometer with insufficient accuracy. In the last experiment design we used the 16-bit accelerometer equipped unit.

Application of 16-bit accelerometer in respiration and heart activity monitoring

In the following experiments we reproduced SCG experiment from Chapter 3.2, but for practical reason the time durations were shortened. Figure 4 again clearly illustrates the physical activity of the proband. In the zoomed part the mechanical heart activity (SCG) can be observed in more detail in comparison with 8-bit results. Such a signal can be used, *eg*, for cough analysis, detailed heart movement or even for monitoring of HRV during demanding exercise. In Fig. 5 there is the HRV signal obtained from the accelerometer during squatting, whereas this was impossible when using 8-bit accelerometer. HRV was obtained by applying a simple 20 Hz high-pass filter.

4 CONCLUSION

The experiments demonstrated the possibilities of applying accelerometer sensors in physiology research. It is clearly proven that the accelerometer can not only monitor the proband's movement but also respiration, mechanical heart activity and physiological activation. The achieved results are very interesting and promising for further research as well as implementation into healthcare devices.

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Erik Vavrinský (Ing, PhD) received his Ing and PhD degrees from the Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in 2002 and 2005. He has carried out postgraduate studies in the area of thin-film microsensors and electrochemical biosensors. At present, he participates in the University education process as a lecturer. His current research interests include design, characterization and testing of sensor systems and bio-monitoring devices. A dominant part of his multidisciplinary research is focused on human physiology.

Daniela Moskaľová (Mgr, PhD) received her degrees of Mgr (2008) in Psychology, and PhD (2012) in Clinical Psychology from Comenius University in Bratislava. She is currently an assistant at the Department of Psychology, Faculty of Philosophy, Comenius University in Bratislava. Her research activities are in the field of cognitive psychophysiology and psychobiology.

Martin Daříček (Ing, PhD) studied at the Slovak University of Technology in Bratislava where he received his PhD degree in the field of device and IC characterization. He has carried out postgraduate studies in IC characterization methods. Currently he focuses on off-chip innovative measuring, testing and bio-monitoring devices design, characterization, development and optimization. He is as well responsible for preparation of low-level firmware schemes. Besides, is he currently responsible for R&D projects management. At present, he participates in the University education process as a lecturer.

Martin Donoval (Ing, PhD) received his master and PhD degrees in electronics from the Slovak University of Technology in Bratislava. He has carried out postgraduate studies in the area of IC design. Afterwards he continued working at the university as a research assistant in magnetic force affected IC sensors design and magnetic force IC sensors. He participated in establishing the Department of Electronic Systems focusing on reliability testing, design of smart electronic systems and off-chip innovative solutions. Today he is responsible for projects, particularly in bio-electronics. As a member of the team he is involved in the development of new prototypes and dedicated integrable electronics and reliability testing.