Posturography device based on accelerometer

Jan Dolinay, Viliam Dolinay, Vladimír Vašek and Petr Dostálek

Abstract**—**this article deals with new device for measuring patient’s tilt in posturography. The device is based on accelerometer which allows it to be very portable, easy to use and also cheaper than commonly used posturography tools based on a strain gauge platform. An application for personal computer was also created which receives the data from the portable unit wirelessly and allows the physician to see and evaluate the results in his/her computer.

Keywords**—**Accelerometer, Atmel AVR, Bluetooth, Posturography.

I. Introduction

THE progress in electronics impacts every area of our life. New parts, such as sensors or microcontrollers make it possible to create devices which would be unthinkable several years ago, or would be too expensive or too bulky. This progress influences also the tools used in medicine, for example, new devices enable easy and cheap testing and diagnostics which earlier required expensive tool and/or laboratory equipment. In this paper we will describe application of such new technology, a triple-axis accelerometer with microcontroller and wireless data transfer, for use in posturography. Posturography is a general term used for diagnostic techniques used to quantify postural control in an upright stance. There are various devices used for the evaluations, including specialized platforms with sensors to provide feedback during the test [1]. The posturography techniques can be divided to static and dynamic.

In the static methods the subject is standing on a fixed platform and his/her ability to maintain standing balance is evaluated. This fixed platform is equipped with sensitive detectors which monitor small oscillations of the body, see fig. 1.

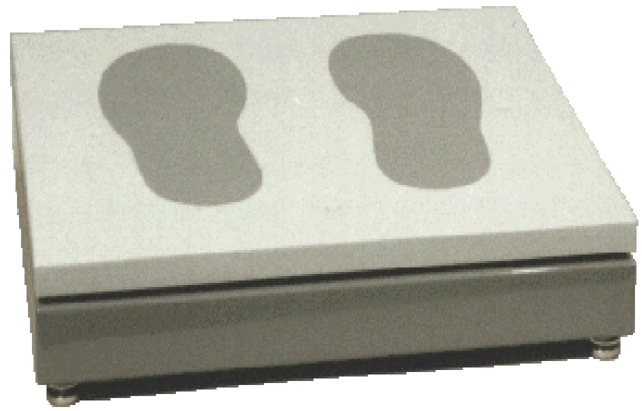

Fig. 1 Example of a platform for static posturography [10]

In the dynamic posturography the subject’s posture is perturbed by the platform [5]. Therefore the platform must be able to move so that the subject’s posture can be perturbed. The results of this method provide measure of the subject’s ability to maintain balance in non-static conditions. Example of the apparatus for dynamic posturography can be seen in fig. 2.

Fig. 2 Computer equipment for dynamic posturography [17]

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Typically, in such posturography test, the patient wears a safety harness in case he/she falls and is positioned on a platform. One of the basic tests involves asking the patient to stand up and hold the position as long as possible.

The tests can be performed with or without visual reference (with closed eyes) and it is also possible to include moving environment which gives conflicting visual information.

In principle the platform provides information about the distribution of the patient's weight. The data are sent to computer which records the changes of the patient's position in time. The record is called posturogram, see fig. 3.

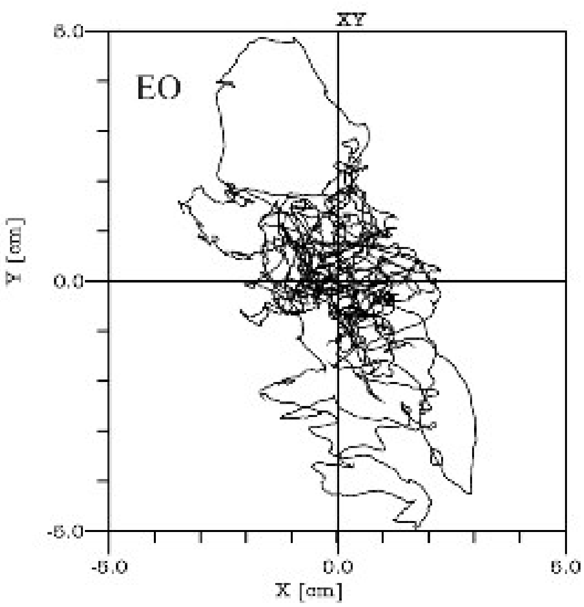

Fig. 3 Example of a posturogram [12]

Naturally, in both the static and dynamic methods described above, there must be some sensors to evaluate the position of the examined patient. Typically these sensors are strain gauges, which are built into the platform. Consequently these methods actually evaluate the center of gravity of the patient.

There are many posturography devices available on the market. However, the price is quite high and not every private doctor or a small hospital can afford such device. For example, the situation in the Czech Republic is such, that modern computerized posturography is available only in bigger hospitals [13].

Another problem may be the availability of the data for processing or storing in other applications. The systems are usually sold as a complete package of proprietary hardware and software which may not be prepared to export or share the data with other programs. Or the process is too complicated. On the other hand, modern physician expects that the results will be available in the software they use, e.g., for their patient's record. This can be perceived as a general situation in (not only) medicine, that there are incompatible software and hardware platforms offered by different manufacturers which the doctor can use together only with difficulties or extra work [4], [14].

In this article we present different approach to measuring the patient's position using modern three-axis accelerometer, which can sense the position of the subject relative to Earth's gravity. The resulting device can be very cheap and small which makes is well suited even for doctors or hospitals who do not deal with patients requiring posturography on a daily basis. In such facilities it is not economically feasible to buy expensive platform and neither is it comfortable to have it occupying the precious space in the consulting room while not used. Having cheap, small and ready to use device for quick screening could be useful.

II. Tilt-measurement device

In this section the tilt-measuring device based on accelerometer is described in detail. It starts with description of the hardware, and then describes the embedded software which runs on this hardware and concludes with software for processing the data on personal computer.

The overall picture of the system can be obtained from fig. 4. The upper part of the picture depicts the embedded device, the tilt-meter, which will be described in the next chapter. This device is attached to the patient and evaluates his/her orientation in space using a triple-axis accelerometer. The accelerometer data are processed by microcontroller and transmitted using a Bluetooth module.

On the receiving side there is a personal computer (PC) equipped with necessary hardware to receive Bluetooth transmission (e.g. a Bluetooth dongle or a built-in transceiver). An application for PC was also created as a part of the work described in this article. This application runs on the PC, receives data from the portable unit, calculates actual orientation in space from the received data and presents the results to the user.

A. Hardware design

The device is based on single-chip microcontroller (MCU) Atmel ATmega8L [6]. ATmega8 is low-power, low-cost 8-bit microcontroller from the Atmel AVR family with RISC core. It provides up to 16 MIPS of computing power at 16 MHz. The key parameters include 8 KB of flash memory for the program, 1 KB of static RAM and 512 bytes of EEPROM memory.

The L-version is able to operate with low voltage power supply, from 2.7 V to 5.5 V, while the standard version operates at power supply between 4.5 and 5.5 V only. For our application the low voltage version is needed, because the other components of the system work with 3 V logic levels and power supply [2].

The main sensor in the device is Freescale's MMA7260Q triple-axis accelerometer [7]. This was one of the first sensors on the market with three accelerometers built into single integrated circuit.

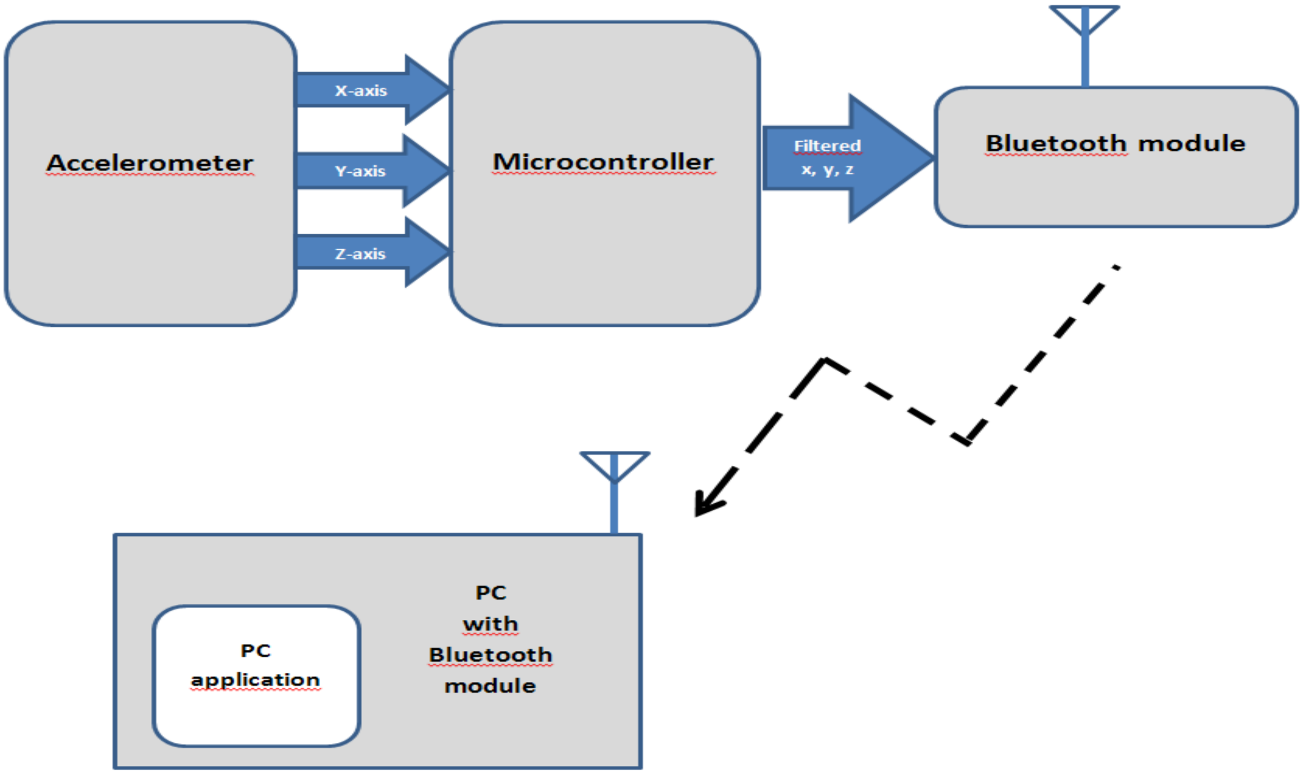

Fig. 4 Block diagram of the system

As the accelerometer itself is very small - a square of 6 by 6 mm with 16 leads at the bottom – it would be hard to use directly in the prototype device. Therefore so-called breakout board was used, which contains the accelerometer and supporting parts to filter the signal on a printed circuit board with pin-header pads, see fig. 5. The breakout board dimensions are 25x25 mm. It is manufactured by SparkFun Electronics [8].

The accelerometer provides three output voltages which represent the acceleration in axes X, Y, Z. The sensitivity is selectable with ranges up to 1.5g, 2g, 4g or 6g. The accelerometer is connected to the Analogue-to-digital (AD) converter contained in the MCU.

One of the requirements on the device was that it should transmit data wirelessly to the doctor's computer. It would be very impractical to make the patient wear the device with long wire connected to the computer.

To allow the wireless data transfer we decided to use a Bluetooth serial module OEMSPA310 [9].

This module, shown in fig. 6, is sold in the form of a small printed circuit board with soldering pads. In our case it is connected to the main board using short wires.

Even though the Bluetooth technology is not ideal from the point of view of reliability and ease-of-use for communication between an embedded unit and a computer, it has two advantages which prevailed for our purpose of creating low-cost prototype:

- there are very easy to use, ready-made modules which can be connected to microcontroller
- these modules are rather cheap.

The Bluetooth module connects to the serial interface (UART) of the MCU and transmits the data over Bluetooth. From the point of view of the MCU program, this is simple serial communication. The MCU program actually does not know it is sending the data wirelessly over the Bluetooth; it just sends the data to serial line.

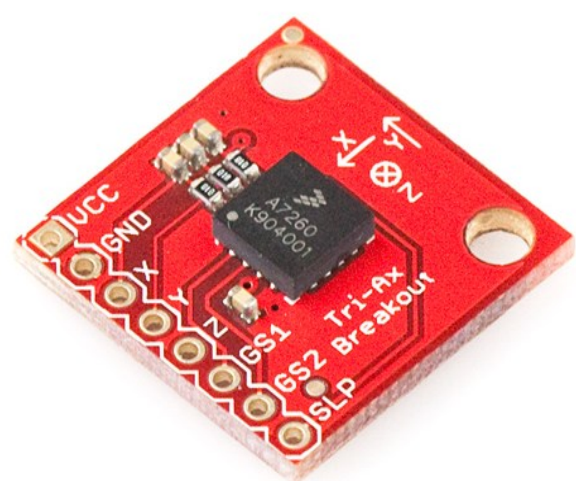

Fig. 5 Breakout board with the MMA7260 accelerometer [8]

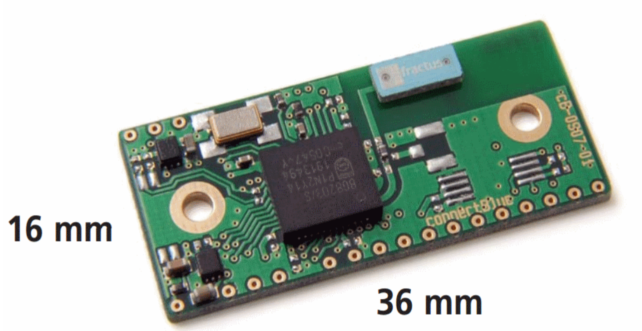

Fig. 6 Bluetooth module OEMSPA310 [7]

On the receiving PC a Bluetooth dongle or similar device is required, unless the PC has Bluetooth interface built in – which is often true with laptops and tablets nowadays. The OEMSPA module relies on Serial over Bluetooth service, which means that the driver for the Bluetooth interface on the PC creates a virtual serial port and the application running on PC communicates through this serial port.

This way also the communication part of the PC application is relatively simple as it sends/receives the data using standard routines for communication over serial port.

The tilt-meter is powered from batteries – three rechargeable cells of AAA size are used. The device has also a simple charger circuitry integrated, to allow recharging the batteries comfortably without the need to remove them from the unit.

The device consists of a main printed circuit board with the MCU and supporting electronics, the breakout board with the accelerometer and the Bluetooth modules. All is included in a box with dimensions approximately 100 x 60 mm, as can be seen in fig. 8 and fig. 9.

Functional block diagram can be seen in the fig. 4 earlier in this chapter. As already mentioned, the accelerometer provides three voltages which are in ratio to the acceleration the device senses in the three axes. These voltages are evaluated by the MCU thru its built-in AD converter. The MCU converts and filters the data and sends them to the Bluetooth adapter, which then transmits them to the PC.

Fig. 7 shows the schematics of the main printed circuit board of the device. The core of the device is the 8-bit MCU described earlier. It requires only few external parts for its operation, such as filter capacitors and a pull up resistor on the Reset line. The clock is provided by internal oscillator, which has sufficient precision for our purpose.

The power for the board is provided by voltage regulator LP-2950 which provides stable 3 V level from the input voltage of three NiMH cells, which power the device. This regulator powers the MCU and also the external modules (accelerometer and Bluetooth) which are connected to pin-headers JP1 and JP2.

The circuit also contains a simple battery charger (a current source) with LM317 integrated circuit which charges the NiMH batteries. The voltage of the batteries is also available on the input of the MCU, so that it can warn the user when the batteries need to be charged by flashing LED1.

In normal operation the device is powered from the batteries, but it contains a DC jack for connecting power adaptor to charge the batteries. As already mentioned, the MCU monitors the voltage on the batteries and warns if they are discharged using a LED. It also controls the charging process.

The prototype of the device is fitted in a box with dimensions 100 by 60 mm, see fig. 8. On the side there is a push-switch to turn it on/off, and an LED to indicate the state of the device. On the opposite side there is a DC power jack connector input. The device is attached to patient's back by means of a belt with Velcro fastener.

B. *Embedded Software*

This chapter deals with the software for the 8-bit microcontroller used in the portable unit. The software is written in C language and built using the development tools provided by the MCU manufacturer – an integrated development environment called Atmel AVR Studio which uses AVR-GCC compiler.

The operation of the firmware is relatively simple. It sends data to the PC at fixed interval of about 20 ms. These data are obtained as a reading of several samples (e.g. 15) from all the axes with about 1 ms period and computing medians of these samples. The resulting values are then sent to PC and new measurement is carried out. As already mentioned the data are sent wirelessly using a Bluetooth module. This module is connected to the UART interface of the MCU, so the firmware actually sends the data to simple serial line and the external Bluetooth module handles the conversion to wireless standard and transmitting it. The data can be sent either in text or binary format.

The text format is used for testing the program, as it allows easy reading in any terminal program on PC. The format of the text data is as follows:

X=yyyy Y=yyyy Z=zzzz ID=iiii U=uuuu st=s

Where the "xxxx", "yyyy" and "zzzz" are the values of the acceleration in the respective axes. These values are sent in the form of raw values obtained from the ADC (integer numbers). The ID is identifier of the device, the U is the voltage of the batteries sent as integer which represents the actual voltage multiplied by 100. For example, value of 300 means the voltage is 3.0 V.

Finally the "st" is the status of the device. It is given as a simple number which represents a state as defined in the program, such as full battery, low battery, charging etc.

For sending the data in normal mode, when the device communicated with the program on PC binary format is used to allow higher data throughput.

The format of the binary data is as follows (hexadecimal and symbolic representation, spaces added between bytes for better reading):

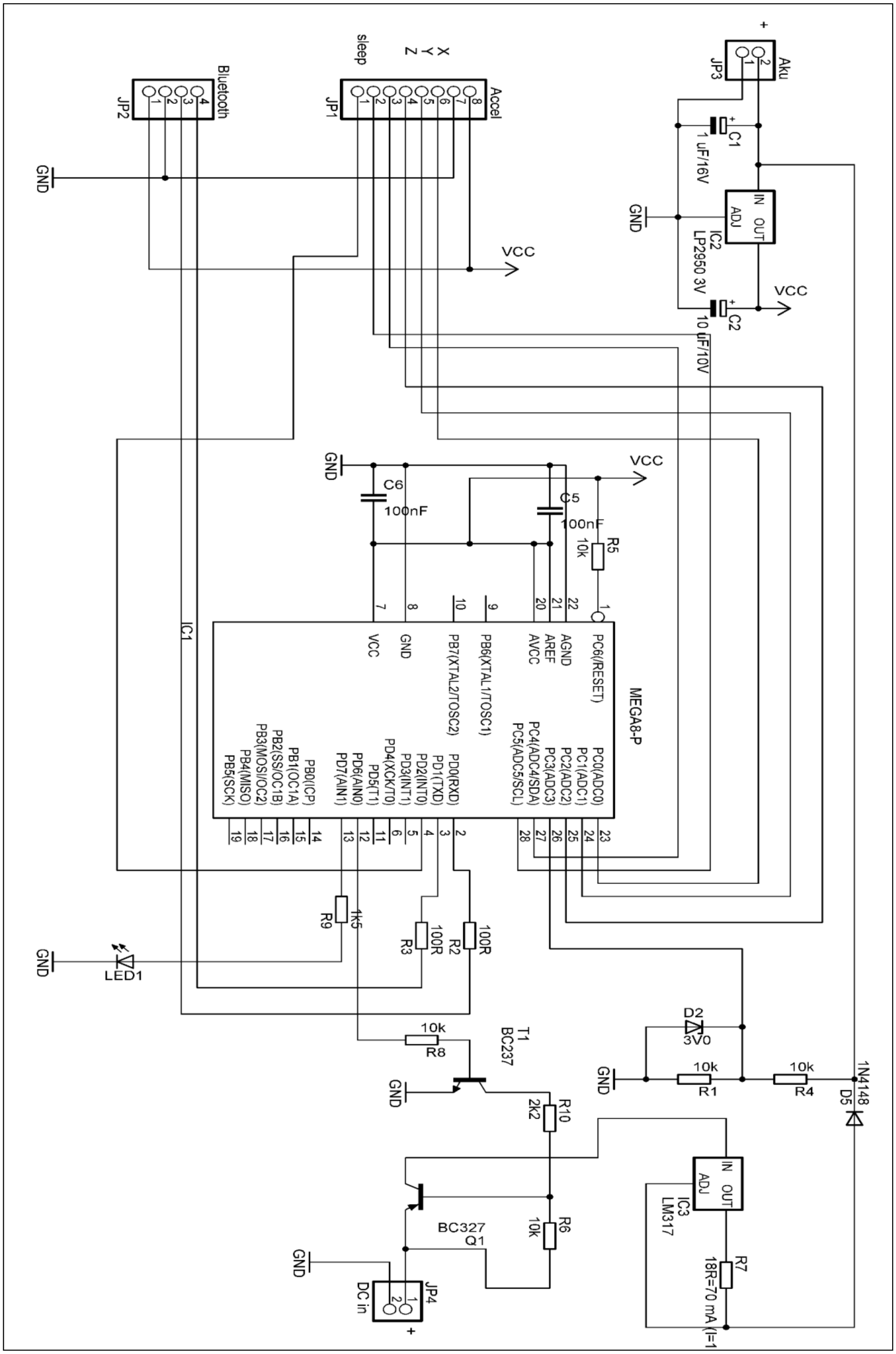

Figure 7 – Schematics of the main board

FF FF xx xx yy yy zz zz ii ii vv vv.

The meaning of the symbols is the same as for the text format, but instead of being sent as alpha-numerical characters, the values are sent as raw numbers. Each value is 2-bytes wide. Two bytes with FFFF value at the beginning represent a start-of-packet marker. The last value "vv" is the voltage of the battery.

Figure 8 – Prototype of the device

Figure 9 – The internals of the device

III. PC Application

As a part of the work an application for PC was also created which processes and visualizes the data from the portable unit. This application receives data thru virtual serial port (created by the Bluetooth driver) and calculates the orientation of the unit, or the patient respectively. The main screen of the application can be seen in fig. 10.

The user interface of the program is rather simple. At the top menu there are actually only 3 commands: Settings, Help and Exit.

The settings window allows entering the number of the serial port to be used for communication and folder where the results should be stored (in a simple plain-text format).

In the main window, there is a text box for identification of the patient at the top. Below this box there is "Calibrate" button which is used to calibrate the unit before the test is executed. In the areas below this button there are simple charts drawn of the patient's tilt for both open eyes and closed eyes test. There are also basic values displayed, such as the distance travelled or area covered by the tilt, which are computed from the received data.

There is also an option to copy the data to clipboard. Besides this export, the data can also be obtained from a text file which is automatically created after the measurement.

The application is indeed rather simple and provides only basic information, but it is primarily intended for evaluation of the device. In future, the application should be improved.

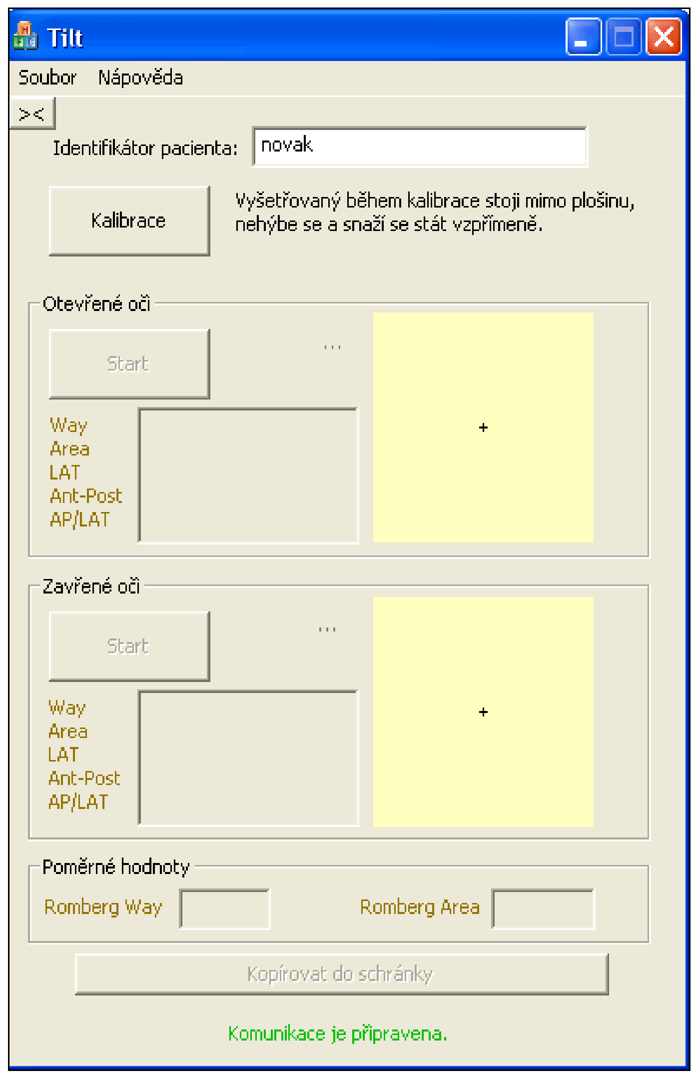

Figure 10 – The application for PC

IV. Verification and Discussion

The device was tested both in "amateur" conditions by the developers and by a physician. The results for two subjects can be seen in fig. 11 through fig. 14. The tilt is always displayed in degrees in these figures.

It proved that the device is usable, yet some disadvantages of this approach exist. The main drawback seems to be difficult interpretation of the results. As the device is based on different principle than the commonly used platforms, the results are not easily comparable. This device measures the orientation of the patient - or the device itself to be more exact - in Earth's gravity. We can also say that it measures the tilt of the patient. On the other hand, the platforms used for posturography are based on strain gauges and measure the movement of the patient's center of gravity. In consequence, the charts and other results from this new device cannot be interpreted in the same way as the results from a platform. And as the device is new, there is no experience with the interpretation of the results. To describe the problem in simple words, the doctors do not know what the charts obtained from this device mean because they are used to charts from devices working with different principle, which naturally look different.

This drawback could be solved by providing a way of transforming the result of the new device into outputs similar to that of those obtained by strain-gauge based platforms based methods. Another option would be to provide automatic evaluation of the results, based, e.g. on a neural networks. This remains a topic for further improvement.

Nevertheless, this device is functional and could be useful for quick screening with automated software analysis of the results and detect patients with problems which would then be further checked using more precise method.

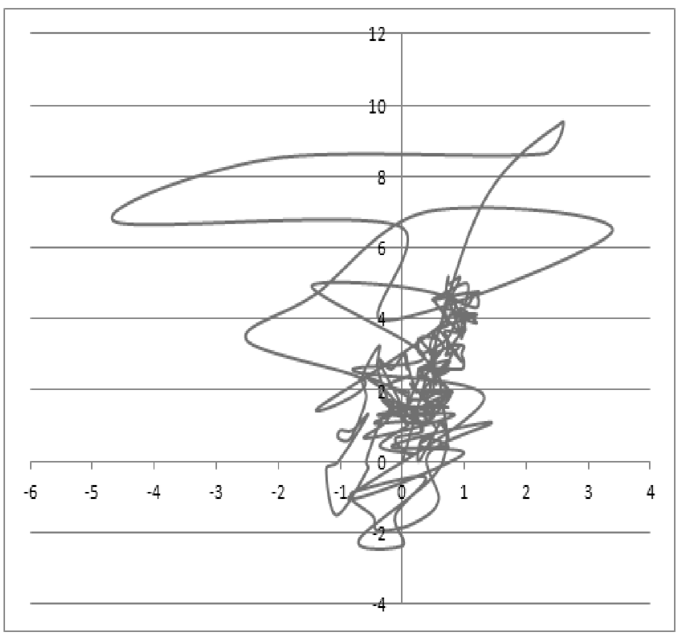

Figure 11 – Subject 1, Surface plot of view from above in x/y projection

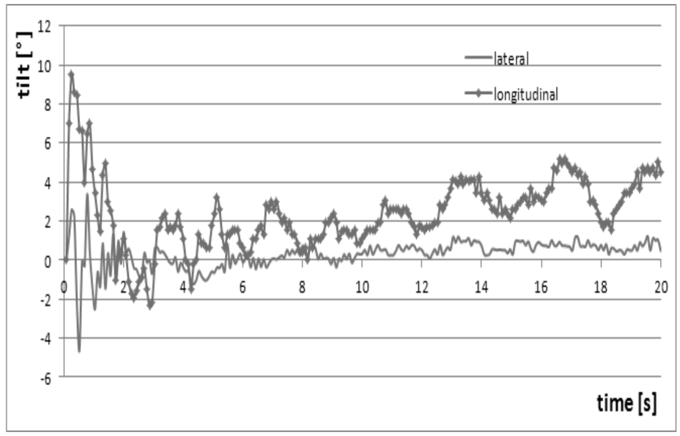

Figure 12 – Subject 1, Time-extension plot in x/t; y/t derivation

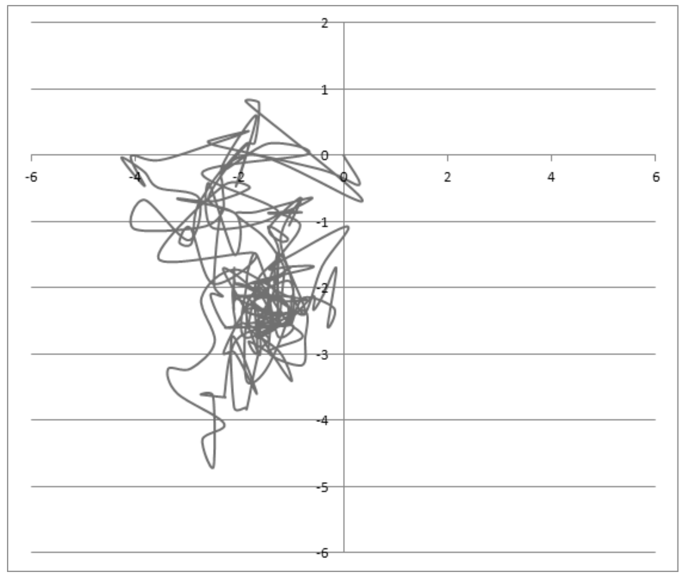

Figure 13 – Subject 2, Surface plot of view from above in x/y projection

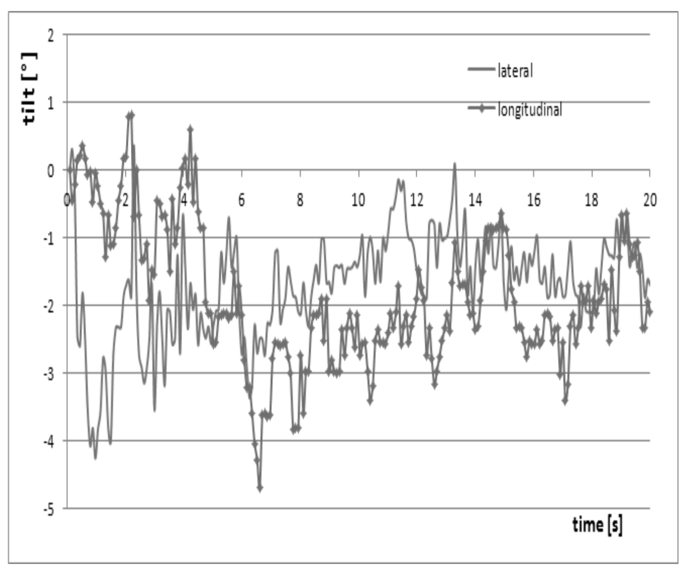

Figure 14 – Subject 2, Time-extension plot in x/t; y/t derivation

V. Conclusion

This article described small portable device which could be used for posturography. Thanks to modern electronics parts, namely triple-axis accelerometer, the device can be small, cheap and yet provide useful results. The device is a portable unit which is attached to the patient and sends measured data into a personal computer over Bluetooth interface. The computer then processes these data to calculate the orientation of the unit (and the patient) is space, records the results and shows it to the user (a doctor) in a chart.

Practical experiments showed that the device is working properly. However, some problems, mainly the interpretation of the results and its comparison with traditional posturography methods, remain to be solved before it could be widely adopted in the practice.

References

[1] L. Pivnickova, V. Vašek, V. Dolinay, “Examinations and algorithms to help find a cause of vertigo”, *International journal of mathematical models and methods in applied sciences*, Vol.5, No.7, 2011, pp. 1273-1280.

[2] J. Dolinay, V. Dolinay, P.Dostálek, V. Vašek, “Tilt-measuring device for Posturography”, *In Proc. Recent Researches in Medicine, Biology and Bioscience*, Crete Island, Greece 2013, pp. 149-151, ISBN 978-960-474-326-1.

[3] L. Pivničková, V. Dolinay, V. Vašek, “Application of Fuzzy Logic in the Evaluation of Postural Stability”, *In Proc. Recent Researches in Medicine, Biology and Bioscience*, Crete Island, Greece 2013, pp. 144-148, ISBN 978-960-474-326-1.

[4] V. Dolinay, V. Vašek, V. Zlínský, U “Software utility for processing of hearing investigation results”, *Annals of DAAAM for 2005 & Proceedings of the 16th International DAAAM Symposium*. 2005, p. 99-100. ISBN 3-901509-46-1.

[5] *Vestibular Technologies, Posturography*, Available: http://www.vestibtech.com/Posturography.htm

[6] *Atmel Corporation, ATmega8 overview*, Available: http://www.atmel.com/devices/atmega8.aspx.

[7] *Freescale semiconductor, MMA7260Q Datasheet*, Available: http://cache.freescale.com/files/sensors/doc/data_sheet/MMA7260QT.pdf?pspll=1.

[8] *SparkFun Elenctronics, Triple Axis Accelerometer Breakout - MMA7260Q.* Available: https://www.sparkfun.com.

[9] *connectBlue, OEM Serial Port Adapter – Bluetooth module OEMSPA310*, Available: http://www.connectblue.com/products/classic-bluetooth-products/classic-bluetooth-modules/bluetooth-module-oemspa310.

[10] *Caretta s.r.o., Posturography*, Available: http://www.caretta.cz/software/posturograph/teorie.asp

[11] *Ear Associates Rehabilitation Services, Inc., Balance therapy*, Available: http://www.earassociates.com/services-balance-disorders-san-jose-ca.html

[12] L. Czerwosz at al., “Analysis of Postural Sway in Parients with Normal Pressure Hydrocephalus: Effects of Shunt Implantation”, *European Journal of Medical Research*, vol. 14, pp. 53-58, 2009.

[13] L. Pivničková, V. Dolinay, V.Vašek, R. Jašek, “Verification of the Examination Results by Digital Signature”, *In Proc. Recent Researches in Medicine, Biology and Bioscience*, Crete Island, Greece 2013, pp. 152-156, ISBN 978-960-474-326-1.

[14] V. Dolinay, L. Pivničková, V.Vašek, “Computerization of Audiometric Examination”, *In Proc. Recent Researches in Medicine, Biology and Bioscience*, Crete Island, Greece 2013, pp. 152-156, ISBN 978-960-474-326-1.