Design and Development of a Portable WiFi enabled BIA device

D Krizaj¹, M Baloh², R Brajković, T Žagar³
¹University of Ljubljana, Faculty of Electrical Engineering, Tržaška cesta 25, 1000 Ljubljana, Slovenia
²University of Ljubljana, Faculty of Computer and Information Science, Tržaška cesta 25, 1000 Ljubljana, Slovenia
³Geodetic Institute of Slovenia, Jamova cesta 2, 1000 Ljubljana, Slovenia

E-mail: dejan.krizaj@fe.uni-lj.si

Abstract. A bioimpedance device (BIA) for evaluation of sarcopenia – age related muscle mass loss – is designed, developed and evaluated. The requirements were based on lightweight design, flexible and user enabled incorporation of measurement protocols and WiFi protocol for remote device control, full internet integration and fast development and usage of measurement protocols. The current design is based on usage of a microcontroller with integrated AD/DA converters. The prototype system was assembled and the operation and connectivity to different handheld devices and laptop computers was successfully tested. The designed BIA device can be accessed using TCP sockets and once the connection is established the data transfer runs successfully at the specified speed. The accuracy of currently developed prototype is about 5% for the impedance modulus and 5 deg. for the phase for the frequencies below 20 kHz with an unfiltered excitation signal and no additional amplifiers employed.

1. Introduction
One of the first practical uses of the bioimpedance measurement technique (BIA) was evaluation of the content of water in the human body [1], [2]. The basic underlying principle for estimation of water content is based on a fact that water is much better conductor of electric current than the neighboring tissues. An improvement of the technology was achieved by using four electrode measurements with surface electrodes [3]. Usually, for BIA measurements of the whole body mass, two current injecting electrodes are placed on the hand and foot and close to them are placed two voltage electrodes. From measured bioimpedance data several parameters are determined such as index of fat free mass (FFM), total body water (TBW), extracellular and intracellular water content (ECW and ICW) etc. (see for instance [4]).

Our aim was to develop a simple and yet sufficiently accurate device that would be particularly adapted for BIA use for determination of TBW in elderly persons that are hospitalized and more or less immobilized. There is a serious concern in evaluation of loss of muscle mass due to prolonged immobility. The term used for age related loss of muscle mass is sarcopenia [5]. This loss of muscle mass with aging is hypothesized to have negative consequences for health and physical functioning in old age. Several models for evaluation of loss of muscle mass using BIA are known from the literature.
As a result of our investigation of the state of the art technologies, devices on the market and the requirements of the end users (medical doctors) we decided to base our BIA system on the following requirements:

- the device should be low weight and portable, battery powered
- use of low cost technology based on microcontroller with possible integrated AD/DA converters
- the measurement based on digital lock-in technology
- measured data should be transferred by WiFi to handheld devices or laptops
- models for evaluation of sarcopenia using BIA should be modified by the user or even self-declared
- the transfer protocol should enable creation of an internet enabled database

In the following we present current state of design and development and some issues indicating further research and development.

2. Hardware

The presented device design is based on physical separation of the measurement part and the data analysis part. The measurement part (Figure 1) is based on a commercial 32-bit microcontroller with embedded A/D and D/A converter. D/A converter operates at 1 MHz with resolution of 10 bits and is used for sine wave generation. The generated sine wave is low pass filtered and applied to the current electrodes. The resulting voltage drop is picked by an instrumentation amplifier with a high CMRR and the resulting current is led to an operational amplifier operating as a current to voltage converter. Both signals are digitized by microcontroller's A/D converter with resolution of 12 bits and frequency of approximately 90 kHz. Undersampling was used for the frequencies above 45 kHz. The signal generation and the data acquisition are performed simultaneously using timer interrupts for the signal generation and direct memory access for the A/D conversion. Communication between the computer and the measuring device is established through an Ad-Hoc WiFi connection. Once the voltage and current wave forms are acquired they are sent to the computer for analysis and presentation.

The bioimpedance measurement is based on a digital lock-in method. We decided not to perform data analysis on the microcontroller but rather on a remote computer that can be either a notebook, a smart phone or a tablet, because these devices are already common equipment in every laboratory or institution and very powerful portable computers can be obtained at low cost. Another advantage is that we are able to modify or improve the algorithms according to users’ requirements and wishes without reprogramming the microcontroller.

3. Software

Communication between the device and the computer is performed through a telnet connection. The application listens on an open port and connects to the device, once the device requests a connection. The communication protocol was tailored to the device. It uses a 4 byte instruction word. Each 4 byte instruction is made of two sections: a 2 byte instruction identifier, followed by 2 bytes of data. The required sequence of events for a completed measurement is also defined by the protocol. The device announces the start of a measurement with the MEASURE instruction. After this, the device sends one-time parameter information. These include the parameters the device is using in the current measurement. After all the one-time parameters are sent, a DTST (Data start) instruction is sent by the device, which signals the end of the parameter gathering phase. In the next phase, all received data is
interpreted as measurement data, and no longer as instruction-data combinations. Telnet ensures packets are received reliably and in their proper order, so indexing of the data is not required during transport. Each data value is an unsigned 2 byte integer. The allowed values are from 1 to FFFF(hex). This phase continues until the STOP instruction is received, which is a 2 byte value 0.

A query-response style of communication also exists in the opposite direction. The application can query the device for configuration values, without announcing itself. It sends a 4 byte instruction to the device and receives a 4 byte instruction-data combination as a reply.

The software is written in Java programming language so it is easily portable to different operation systems including modern handheld devices.

4. Usage

Usage of the device is similar to usage of other BIA devices with the difference that all the settings and measurements are set remotely on a laptop or a handheld device (Figure 2).

The BIA device is only switched on or off, performs the measurements in accordance to the received commands using the communication protocol described in Chapter 3 and reports (sends) the measured data to the remote device for further evaluation. The designed BIA device can be accessed using TCP sockets over a wireless Ad-Hoc connection to the RN-XV WiFly module which is connected to the microcontroller via hardware UART interface and operates at a baud rate of 115200 bps. Tests performed using experimental device showed about one second is needed to establish the connection between a computer or a handheld device and the WiFly module when connecting for the first time. Once the connection is established there are no further delays and the data transfer runs successfully at the specified speed (115200 bps). This approach brings several advantages to the BIA measurements and evaluation such as improved portability, decreased cost, flexibility in software design and processing, direct internet connectivity, etc.

5. Test results

Preliminary measurements using a simple UI method (Figure 3) were performed to estimate the accuracy of the device when using only the microcontrollers embedded ICs. The reference resistor (R) of approximately the same value as the expected impedance under test (IUT) modulus was connected in series between IUT and the ground. The voltage drop on the reference resistor and the IUT (the applied voltage) and the voltage drop only on the reference resistor was measured.

The test was performed on the three different RC circuits (Figure 4) with nominal values of 33 Ω for R1 and 100 nF for C1. The value of R2 was 10 Ω, 100 Ω and 1 kΩ for each test case (I, II and III), respectively.

The measurements were performed at 6 different frequencies in the range from 1 kHz to 40 kHz. The upper frequency limit was set by the sampling frequency of the microcontroller as for higher frequencies undersampling was required but for the test circuit without a low pass filter the results were erroneous and not comparable to the low frequency range. The measured values were compared to the reference values measured by a Quadtech 1920 LCR meter. The results of the test are summarized in Table 1 and Table 2.
Table 1. Mean modulus and phase measurement error (calculated from the mean of 10 repeated measurements)

| Frequency | I   | II  | III | I   | II  | III |
|-----------|-----|-----|-----|-----|-----|-----|
| 1 kHz     | -1.66 | 0.00 | -0.61 | -0.0 | 0.1 | -0.2 |
| 2 kHz     | 1.27 | -0.15 | 0.27 | -2.0 | 0.1 | -0.0 |
| 5 kHz     | 0.28 | -0.33 | -0.57 | 1.8  | 0.7 | 0.3  |
| 10 kHz    | 2.43 | 2.10 | 0.48 | 6.0  | 1.0 | 0.6  |
| 20 kHz    | 0.11 | 0.48 | 0.80 | 9.9  | 2.1 | -0.1 |
| 40 kHz    | 9.36 | 2.16 | -9.08 | 14.1 | 3.2 | 18.7 |

Table 2. Standard deviation of modulus and phase measurement error (calculated from 10 repeated measurements)

| Frequency | I   | II  | III | I   | II  | III |
|-----------|-----|-----|-----|-----|-----|-----|
| 1 kHz     | 5.59 | 0.78 | 1.62 | 3.3 | 0.5 | 0.7  |
| 2 kHz     | 2.29 | 1.10 | 1.04 | 5.8 | 1.2 | 0.5  |
| 5 kHz     | 1.28 | 1.31 | 1.33 | 1.5 | 0.4 | 0.6  |
| 10 kHz    | 2.76 | 1.55 | 2.04 | 3.7 | 0.9 | 0.8  |
| 20 kHz    | 6.95 | 1.93 | 2.28 | 2.3 | 0.6 | 0.5  |
| 40 kHz    | 5.06 | 4.04 | 1.03 | 2.1 | 1.7 | 0.8  |

6. Conclusion

Design, development and evaluation of a bioimpedance measurement device (BIA) to be used in particular for estimation of sarcopenia - loss of muscle mass in elderly population – is presented. The concept is based on use of low cost technology based on a microcontroller with integrated AD/DA converters and WiFi protocol to transfer measured data to a remote computer for data analysis and evaluation. The remote device (can also be a handheld smart phone) is used to set all necessary anthropometric data, select or even design users own evaluation protocol (model) and trigger the measurements. The connection between a laptop or a handheld device and the BIA device using WiFi technology is established in less than one second and after that operates practically without delays (at baud rate of 115200 bps). With current design it is possible to develop a BIA device with accuracy in the frequency range below 20 kHz of approximately 5 % for the impedance modulus and 5º for the impedance phase using only the microcontroller’s embedded ICs. The frequency range and the accuracy could be extended with appropriate low pass filtering and undersampling methods. Further improvements in accuracy could be achieved by usage of external fast and more accurate AD/DA converters.

References

[1] Thomasset A 1963 Lyon Med. 209 1325–52
[2] Thomasset A 1962 Lyon Med. 207 107–18
[3] Hoffer EC et al 1969 J. Appl. Physiol. 27 531–4
[4] Kyle U G, et al 2004 Clin. Nutr. 23 1226–43
[5] Visser M 2009 J. Nutr Health Aging 13 713–6
[6] Tengvall M 2009 Clin. Nutr. 28 52–8