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Non-iterative parameter estimation of the 2R-1C model suitable for low-cost embedded hardware

Key words: 2R-1C model; Embedded systems; Parameter estimation; Non-iterative methods; Quadratic interpolation

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Motivation

1. Parameter estimation of the 2R-1C model is usually performed using iterative methods that require high-performance processing units. Consequently, there is a strong motivation to develop less time-consuming and more power-efficient parameter estimation methods.

2. Such low-complexity algorithms should be suitable for implementation in low-cost and widely used microcontroller-based devices.

3. Such an approach ensures high system portability and autonomy, which is very important for applications where handheld devices are needed for real-time estimation at the measurement.

Main idea

1. Input data are measured real and imaginary parts of impedance of the 2R-1C circuit.

2. The characteristic frequency of the 2R-1C circuit can be obtained from measured data as the frequency at which the absolute value of the imaginary part has the maximum value.

3. We propose a method to improve the accuracy of the characteristic frequency estimation with a quadratic interpolation.

4. The 2R-1C model parameters are subsequently calculated from the real and imaginary parts of the measured impedance using a set of closed-form expressions.

Method

1. The real and imaginary parts of the complex impedance of the 2R-1C model can be written as

$$R(\omega) = \mathrm{Re}\{\underline{Z}(\omega)\} = K\frac{\omega^2 + zp}{\omega^2 + p^2}, \tag{5}$$

$$X(\omega) = \mathrm{Im}\{\underline{Z}(\omega)\} = K\frac{(p - z)\omega}{\omega^2 + p^2}, \tag{6}$$

where *K*, *z*, and *p* are defined as

$$K = \frac{R_1 R_2}{R_1 + R_2}, \tag{7}$$

$$z = \frac{1}{R_2 C_2}, \tag{8}$$

$$p = \frac{1}{(R_1 + R_2) C_2}. \tag{9}$$

Here, *p* is equal to the characteristic frequency of the 2R-1C model.

Method (Cont'd)

We propose the use of quadratic interpolation for more accurate estimation of characteristic frequency p_{corr}:

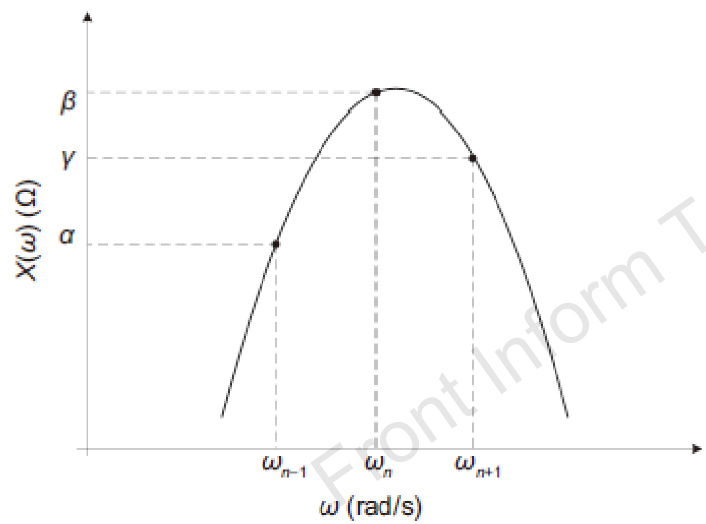

Fig. 4 Values of the imaginary part of impedance around peak β

$$a = -\frac{(\alpha-\beta)\omega_{n+1} - (\alpha-\gamma)\omega_n + (\beta-\gamma)\omega_{n-1}}{(\omega_{n-1}-\omega_n)(\omega_{n-1}-\omega_{n+1})(\omega_n-\omega_{n+1})}, \tag{29}$$

$$b = -\frac{\alpha(\omega_n^2-\omega_{n+1}^2) - \beta(\omega_{n-1}^2-\omega_{n+1}^2)}{(\omega_{n-1}-\omega_n)(\omega_{n-1}-\omega_{n+1})(w_n-\omega_{n+1})} - \frac{\gamma(\omega_{n-1}^2-\omega_n^2)}{(\omega_{n-1}-\omega_n)(\omega_{n-1}-\omega_{n+1})(w_n-\omega_{n+1})}, \tag{30}$$

$$c = \frac{(\alpha-\gamma)\omega_{n-1}\cdot\omega_n}{(\omega_{n-1}-\omega_n)(\omega_{n-1}-\omega_{n+1})} - \frac{\alpha\cdot\omega_n - \beta\cdot\omega_{n-1}}{\omega_{n-1}-\omega_n} - \frac{(\beta-\gamma)\omega_{n-1}\cdot\omega_n}{(\omega_{n-1}-\omega_n)(\omega_n-\omega_{n+1})}. \tag{31}$$

The corrected value of the characteristic angular frequency is

$$\hat{p}_{\text{corr}} = -\frac{b}{2a}. \tag{32}$$

Major results

Simulation

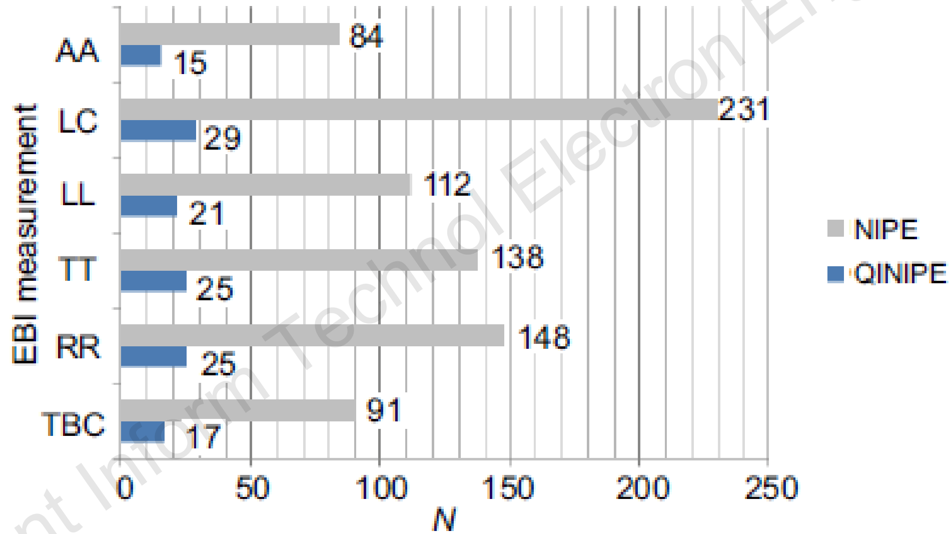

Fig. 9 Comparison of the minimum number of measurement points required for relative errors lower than 1%

TBC: total body composition; RR: respiration rate; TT: trunk-trunk; LL: leg-leg; LC: lung composition; AA: arm-arm

Major results (Cont'd)

Microcontroller-based experiment

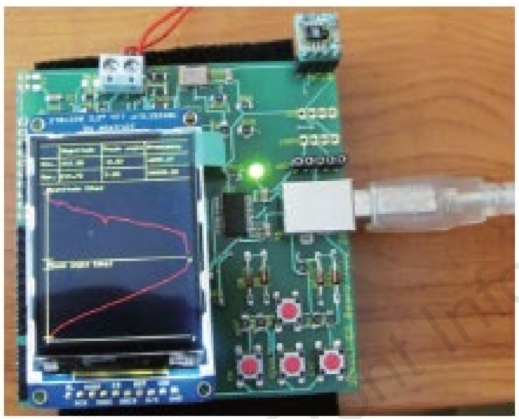

Fig. 10 AD5933-based impedance measurement device

Table 3 Comparison of execution time

EBI	N			t (ms)		
	NIPE	QINIPE	CNLS	NIPE	QINIPE	CNLS
TBC	91	17	17	4.561	5.060	180.621
RR	148	25	25	5.067	5.949	190.501
TT	138	25	25	5.865	7.037	190.925
LL	112	21	21	3.386	4.480	193.935
LC	231	29	29	3.298	4.085	179.834
AA	84	15	15	3.871	3.895	186.247

EBI: electrical bioimpedance; TBC: total body composition; RR: respiration rate; TT: trunk-trunk; LL: leg-leg; LC: lung composition; AA: arm-arm

Major results (Cont'd)

Microcontroller-based experiment (Cont'd)

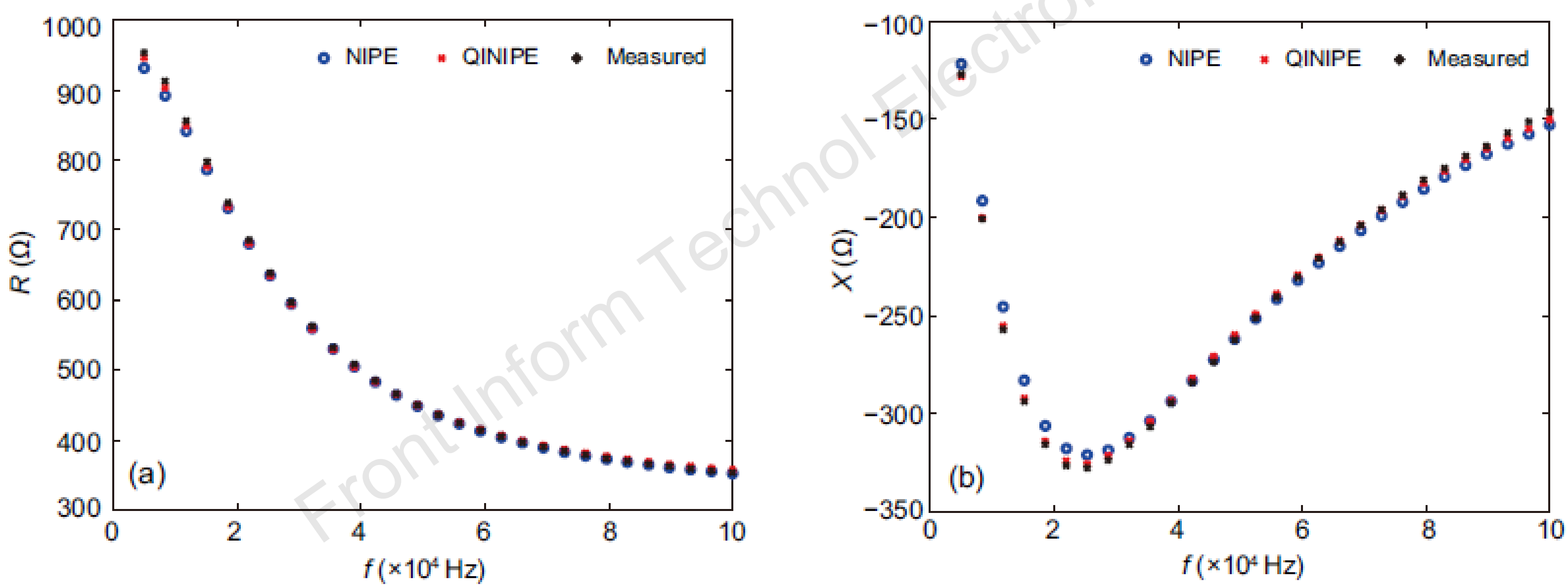

Fig. 14 Comparison of measured impedance and impedance calculated with estimated values of model parameters: (a) real part; (b) imaginary part

Conclusions

1. The QINIPE method, suitable for low-cost embedded hardware, has been proposed for estimation of 2R-1C model parameters.

2. As a result, the accuracy of estimation of all parameters of the 2R-1C model has been improved.

3. Microcontroller-based experiments demonstrated the suitability of the proposed method for implementation on low-cost microcontroller-based devices with limited resources for power consumption, computational complexity, and RAM usage, as well as for applications where portable operation is needed.