5TH CLABIO
LATIN AMERICAN BIOIMPEDANCE
FLORIANOPOLIS – BRAZIL - 2024

Cole-Cole Model and Neural Network for Bioimpedance Analysis of Chicken Tissue

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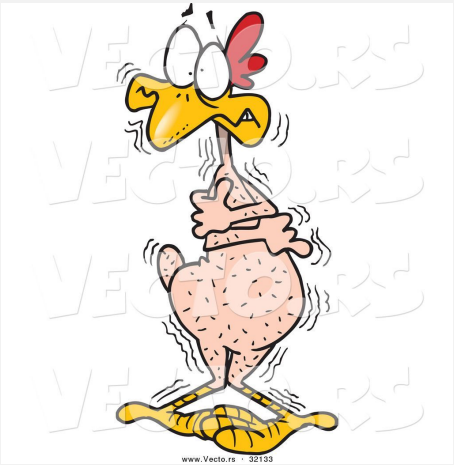
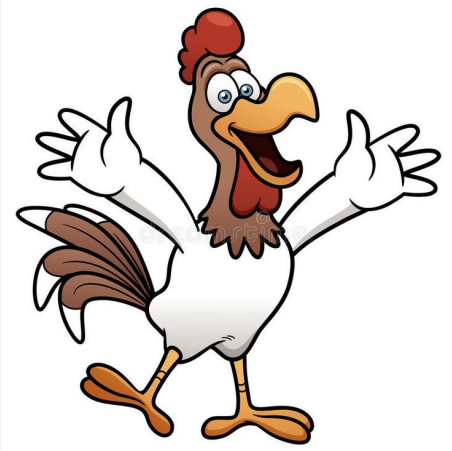
Introduction





Bioimpedance spectra were obtained for frozen and thawed chicken meat samples using the AD5933 development kit from Texas Instruments. These measurements were fitted to the Cole Cole Model using the least squares method. A convolutional neural network - CNN, was designed and trained to classify the freezing process of chicken breast samples using Cole Cole model parameters for the experimental dispersion.

Materials and Methods

$$Z(\omega) = R_\infty + \frac{R_I}{1 + (j\omega)^\alpha R_I C_{cpe}}$$

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Materials and Methods
Bioimpedance Measurements and Calibration

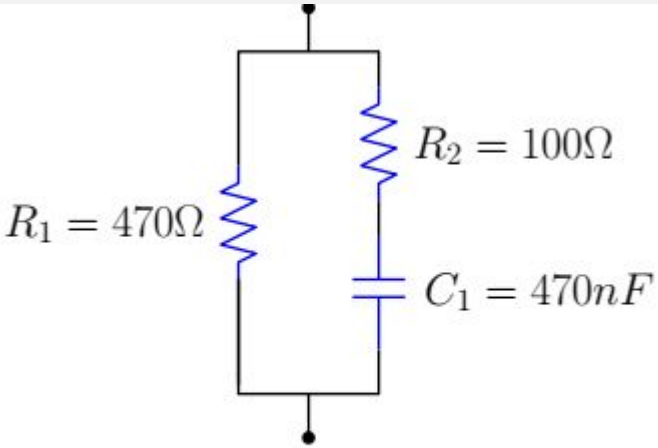
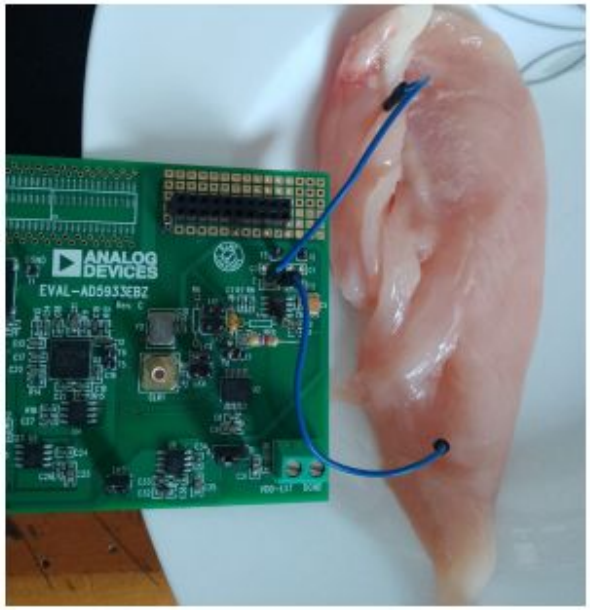


Fig. 1. *AD5933* calibration circuit.

Materials and Methods
Bioimpedance Measurements and Calibration

The electrodes used are nickel-plated copper, with a diameter of 0.5 mm and length of 8 mm, inserted by punching along the samples, while the RC circuit in Figure 1, made with carbon film resistors and a polyester capacitor, was used for calibration of the AD5933, ensuring proper system reliability.



Materials and Methods
Bioimpedance Measurements and Calibration

The Cole model was used to interpret the data, where R_∞ represents the resistive behavior of the medium and R_I corresponds to the ionic conduction inside the cells, interacting with the cell membrane at specific frequencies.

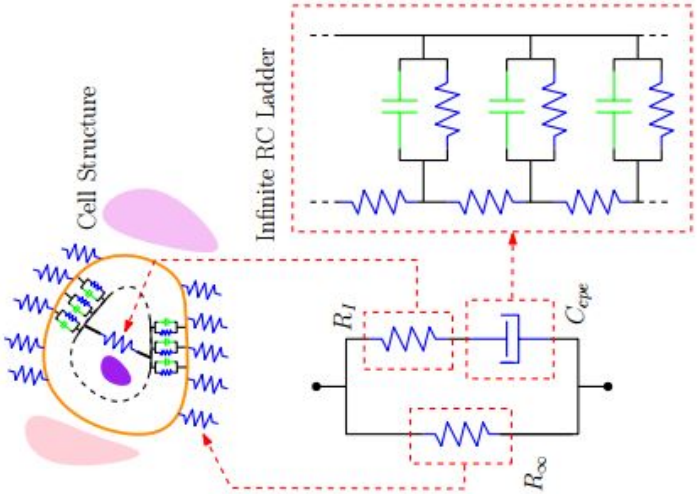
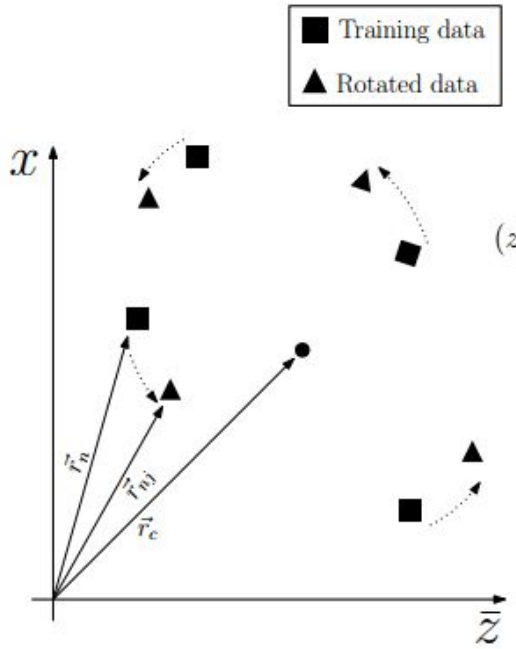


Figure: Cole model used.

Materials and Methods
Training Data Expansion Method



$$\vec{r}_{nj} + \vec{r}_c =$$
$$(z_n, \alpha_n) \begin{bmatrix} \cos(\theta_j) & -\sin(\theta_j) \\ \sin(\theta_j) & \cos(\theta_j) \end{bmatrix}$$
$$\vec{r}_c = \frac{1}{N}\left(\sum_N z_i, \sum_N \alpha_i\right)$$
$$\theta_j \in \left[1, \frac{2\pi}{\sqrt{K}}\right]$$

Figure: Point rotation for convolutional neural network training data expansion.

Results and Discussions
Bioimpedance Data

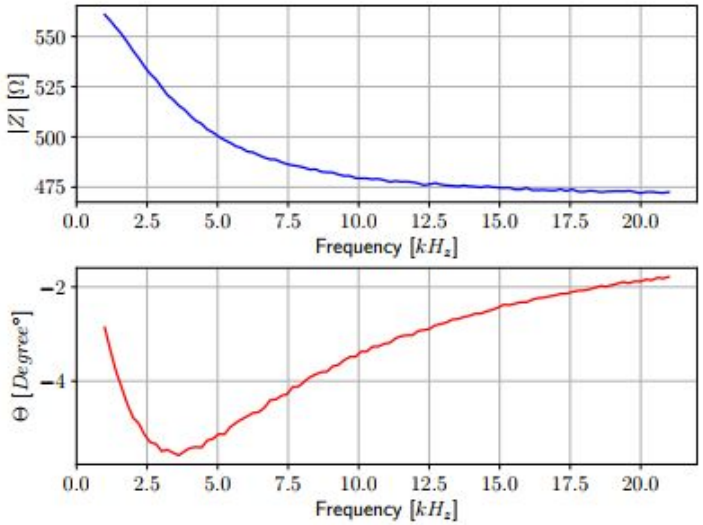


Fig. 5. Bode plot for RC calibration circuit.

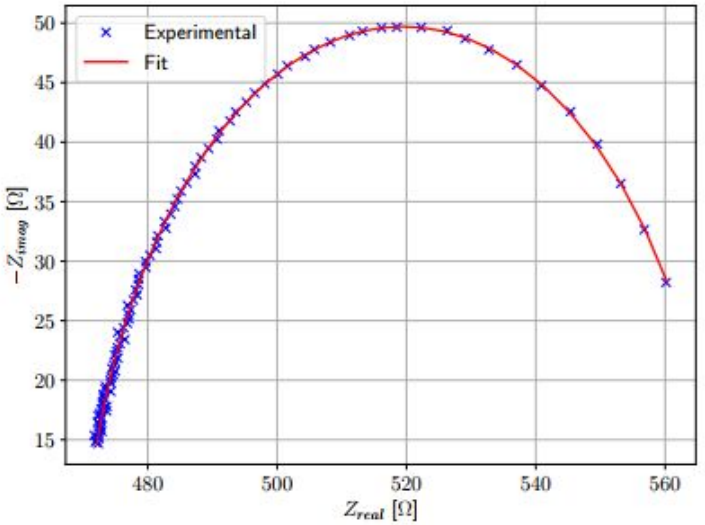
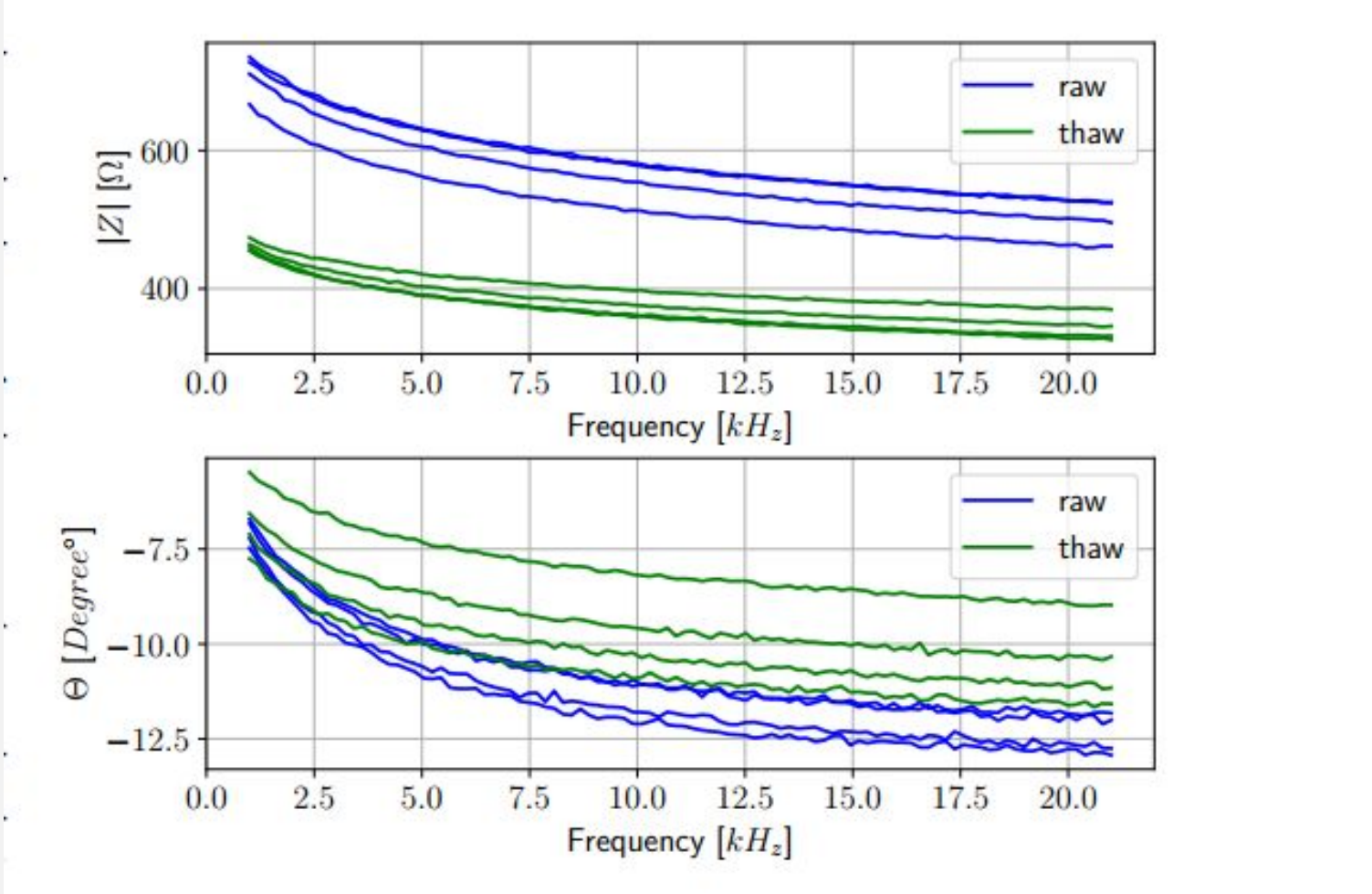


Fig. 6. Nyquist diagram for RC calibration circuit.

Results and Discussions
Bioimpedance Data



Results and Discussions
Bioimpedance Data

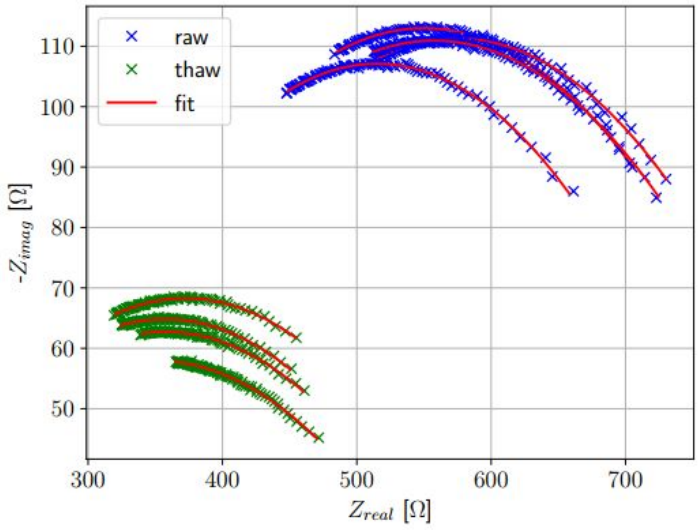


Fig. 8. Nyquist diagram of chicken samples and fit to the Cole-Cole model.

Table 1. Fited values to the Cole-Cole model of chicken samples.

Sample	Condition	α	$C[\mu F]$	$R_I[\Omega]$	$R_\infty[\Omega]$	$\overline{Z}[\Omega]$	$m[g]$
1	Raw	0.42	15.33	660.24	260.12	460.18	535
1	Thaw	0.32	78.48	499.78	119.56	309.67	532
2	Raw	0.40	12.14	638.68	260.56	449.62	498
2	Thaw	0.29	75.28	511.23	110.66	310.94	495
3	Raw	0.43	10.42	678.44	260.21	469.32	562
3	Thaw	0.31	69.28	525.88	96.44	311.16	560
4	Raw	0.41	16.23	644.12	260.25	452.18	450
4	Thaw	0.30	76.56	531.845	95.32	313.58	442

Results and Discussions
Bioimpedance Data

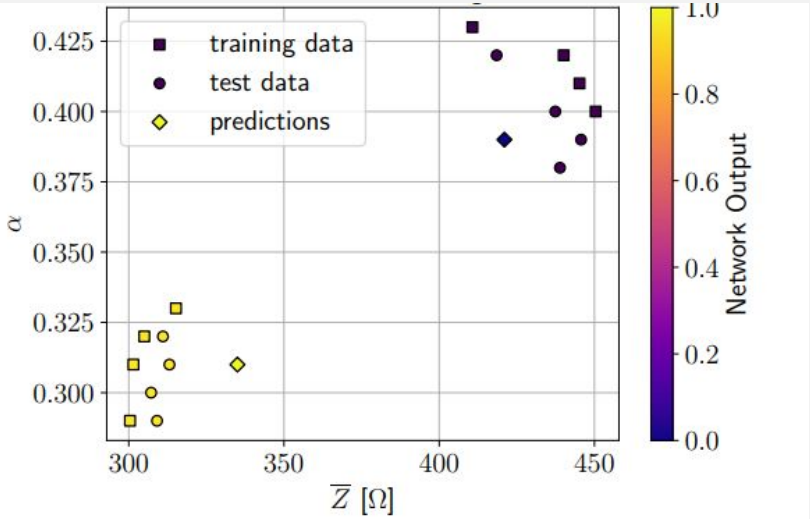


Fig. 9. Convolutional network training results.

Table 2. Experimental error in network prediction of a sample.

Condition	α	$\overline{Z}[\Omega]$	Output
raw	0.39	335.11	0.02
thaw	0.31	421.78	0.95

Why use artificial intelligence instead of visual geometric methods?

X

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Results and Discussions
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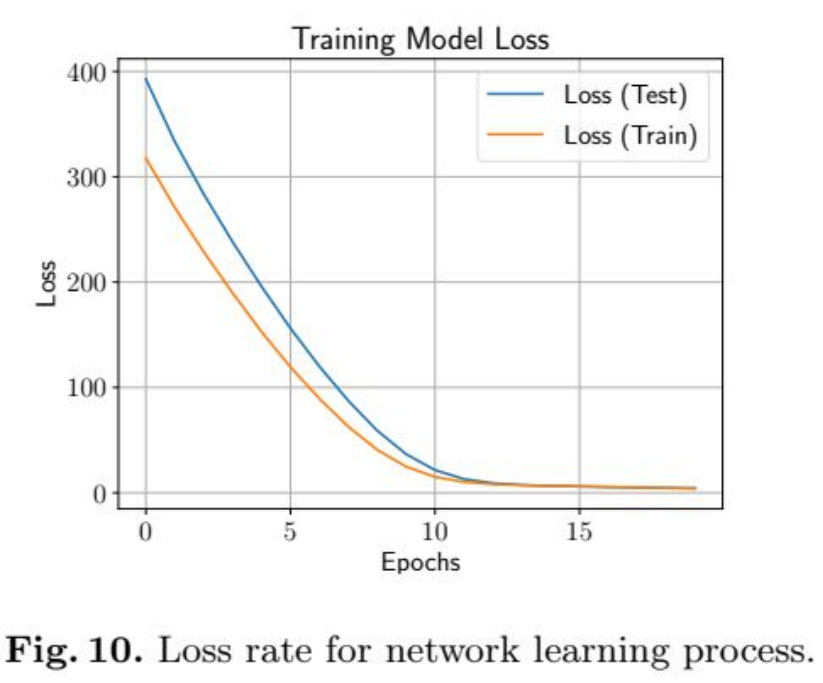

Fig. 10. Loss rate for network learning process.

This parameter shows the evolution of the neural network's learning over training time. As the network begins to identify patterns in the data, the prediction error, represented by the "loss", gradually decreases.

Conclusions

This study analyzed the bioimpedance acquisition system using the AD5933 development kit, with calibration results showing deviations of up to 5% from nominal values, and demonstrated that the Cole Cole model is a reliable tool for BIA data synthesis, simplifying the analysis by reducing the number of parameters.

Thanks funding institution

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