ICT for HEART MONITORING

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PART 3
ECG RECONSTRUCTION

ECG RECONSTRUCTION

Reconstructing a full 12-lead ECG from a reduced lead set is fundamental for diagnosing CADs without clinical equipment

- Limb leads recording can be achieved with minimal invasive technology

- Precordial leads recording is more difficult, but at least a precordial lead is necessary to obtain high reconstruction performance

ECG RECONSTRUCTION

Limb leads are linearly dependent!

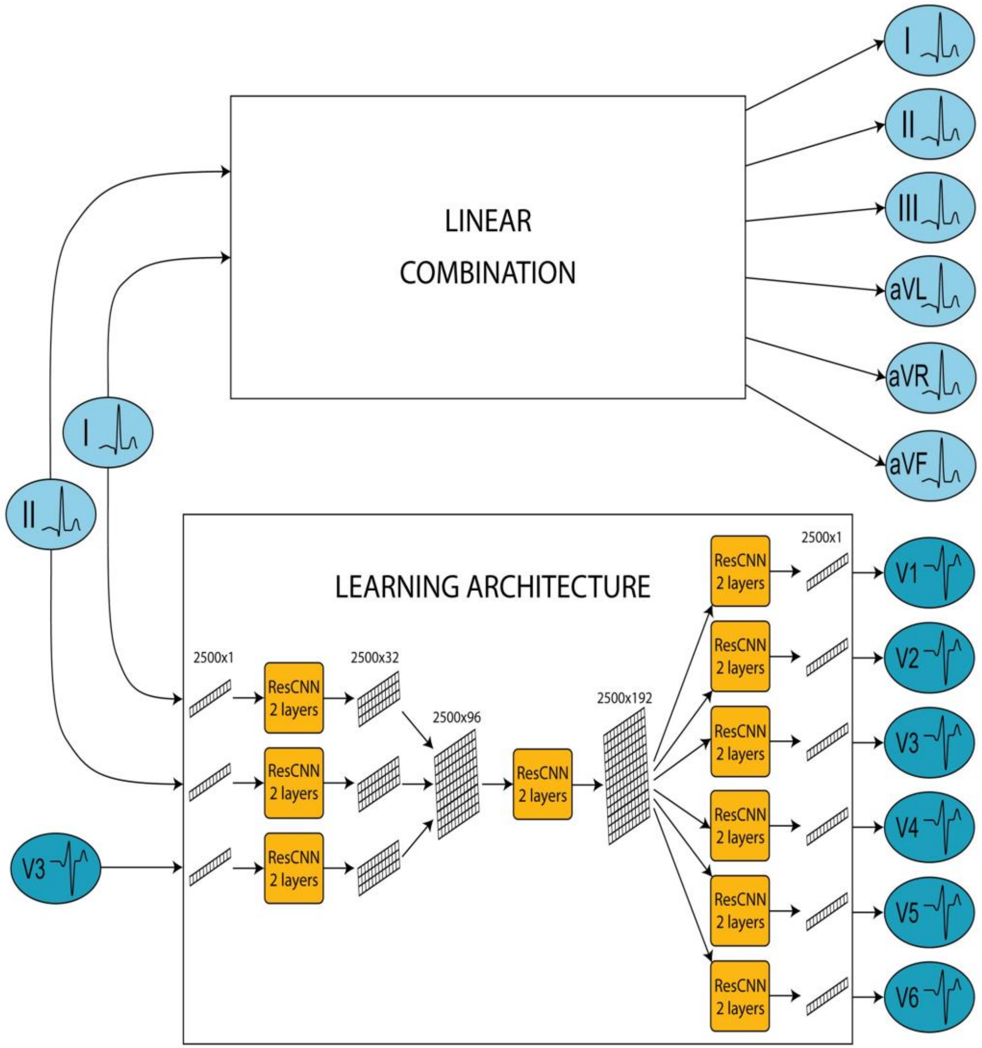
$$III = II - I$$

$$aVR = -\frac{I + II}{2}$$

$$aVR = -\frac{I + II}{2}$$

$$aVL = \frac{I - III}{2}$$

$$aVR = -\frac{I + II}{2}$$



LINEAR REGRESSION (I)

We assume that the missing precordial leads are given by a linear combination of the known leads

$$y(n) = \beta_0 + \beta_1 x_1(n) + \beta_2\, x_2(n) + \cdots + \beta_k\, x_k(n) + \varepsilon(n)$$

where $y(n)$ is the $\mathrm{n^{th}}$ sample of the reconstructed lead, while $x_1(n)$, $x_2(n)$, ..., and $x_k(n)$ are the $\mathrm{n^{th}}$ samples of the input leads

Considering multiple samples and ECG recordings, we obtain a system of N equations

$$\boldsymbol{y} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon}$$

LINEAR REGRESSION (II)

- $\boldsymbol{y}$ is the N-dimensional vector of the reconstructed samples, i.e., the vector of the target variables
- $\boldsymbol{X}$ is the $N \times (k+1)$ matrix having as row the $(k+1)$-dimensional vectors of the input samples, i.e., the vectors of the independent variables
- $\boldsymbol{\beta}$ is the $(k+1)$-dimensional vector of the regression coefficients, where β_0 is the intercept
- $\boldsymbol{\varepsilon}$ is the N-dimensional vector of the error terms

The goal is to minimize the error terms:

$$\min_{\boldsymbol{\beta}} ||\boldsymbol{X}\boldsymbol{\beta} - \boldsymbol{y}||$$

DEEP LEARNING (I)

To better capture the non-linearity that characterized lead relationship, we can design a Deep Learning (DL) architecture that generate a full 12-lead ECG from a subset of the signal leads

$$y = DL(x_1, x_2, \dots, x_k)$$

where y is the reconstructed lead, while x_1, x_2, ..., and x_k are the input leads

We exploit also past and future input samples for reconstructing any missing sample $y(n)$

DEEP LEARNING (II)

Feed-Forward Neural Networks (FNNs) require to define a bias and a weight for each input sample and lead, involving a significant computational cost

- Assuming to implement a single layer, we have a total of $(2N)^2$ parameters to be trained

In Convolutional Neural Networks (CNNs), the number of training parameters depends on the kernel configuration and not on the input dimensionality

- We must tune the kernel size in order to ensure a sufficient high receptive field

PERFORMANCE: QUANTITATIVE MEASURES

A naïve loss function for DL model reconstructing the missing leads is the Mean Squared Error (MSE)

$$MSE(y) = \sum_{i \in (V1,V2,V3,V4,V5,V6)} \frac{1}{6} \sum_{n=1}^{K} \frac{|\hat{y}_i(n) - y_i(n)|^2}{K}$$

The coefficient of determination (R2) is a standardized version of MSE being independent from the scale of the reconstructed signals

$$R2(y) = \sum_{i \in (V1,V2,V3,V4,V5,V6)} \frac{1}{6} \sum_{n=1}^{K} \left(1 - \frac{|\hat{y}_i(n) - y_i(n)|^2}{|y_i(n) - \bar{y}_i|^2}\right),$$

PERFORMANCE: QUALITATIVE MEASURES

Can a cardiologist use a synthetized ECG for diagnose CADs or other heart-related diseases?

- Does a classification algorithm (identifying CADs or other heart-related diseases) obtain the same performance when taking reconstructed and original ECGs as input?
- Can we optimize the reconstruction system towards the maximization of the classification instead of the reconstruction performance?

Thank you!

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