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# The Effectiveness of Using the Pearson's Correlation Coefficient for Compression Quality Assessment: Case of ECG Signals Compression with Discrete Cosine Transform

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**ABSTRACT**

This work presents a comparative study which aims to validate the importance of using the Pearson's Correlation Coefficient (PCC), for the first time in this field of research, as an effective parameter for quantitative measurement of Electrocardiogram (ECG) signal compression quality. The comparison with the Percent of Root mean squared Difference coefficient (PRD) was carried out using the Discrete Cosine Transform (DCT). The ECG signals of the three derivations DI, DII and DIII, used for the test, belong to five categories of patients with various pathologies, each category of which includes four patients. The obtained results, based on the morphology comparison of P waves, T waves and QRS complexes before compression and after reconstruction, showed that the range of values between 99.90% and 100% for the PCC, ensures a very good signal reconstruction quality with a Compression Ratio (CR) that could reach 16.



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## 1. INTRODUCTION

The purpose of compression applied to ECG signals is to minimize and reduce the amount of data for storage or transmission while preserving quality of original information. Compression techniques applied to ECG signals belong to two classes: lossy and lossless techniques. In the case of lossy compression, the reduction in data quantity is large at the expense of quality degradation, while for lossless compression, the quality is better with a small reduction in data size. These techniques that have addressed the problem of compression, often use the CR to measure the amount of data preserved after compression, and the PRD to assess the quality of compression.

The way to objectively evaluate the compression quality of ECG signals is not unified, and there is currently a lack of standardization in this area. Indeed, according to the study carried out in [1], the authors described more than 40 objective methods based on 775 articles consulted in the Scopus database. Among these methods, the most popular or most used are PRD (Percent of Root mean squared Difference coefficient), MPRD (Multichanel PRD), PRDN (PRD Normalized), PRMSD (Percentile Root Mean Square Difference), WDD (Weighted Diagnostic Distortion), SNR (Signal to Noise Ratio), PSNR (Peak SNR), RMS (Root Mean Square error), RMSE (RMS Error), NRMSE (Normalized RMSE), MSE (Mean Square Error), NMSE (Normalized MSE), MAX (MAXimum error), MAE (Maximum Amplitude Error), PE (Peak Error), MaxErr (Maximum Error), NMAE (Normalized MAE), NMAX (Normalized MAX), CC (Cross Correlation), NCC (Normalized CC), WEDD (Wavelet-Energy based Diagnostic Distortion), QS (Quality score) and STDERR (Standard deviation of Errors). The expressions and equations which define these evaluation methods are developed in the relevant articles. Table 1 lists the order of popularity of these methods, where PRD and its variants are the most used ones.

Table 1. Popularity of objective methods used for evaluation of ECG signal quality according to Scopus.

| Objective Methods | Number of articles |
|---|---|
| PRD, MPRD, PRDN, PRMSD | 273 |
| WDD | 126 |
| SNR, PSNR | 93 |
| RMS, RMSE, NRMSE | 78 |
| MSE, NMSE | 60 |
| MAX, MAE, PE, MaxErr, NMAE, NMAX | 55 |
| CC, NCC | 27 |
| WEDD | 23 |
| QS | 21 |
| STDERR | 19 |

Since the PRD does not give, in some cases, a subjective decision on the lossy compression quality, we tried a new parameter which is the Pearson's correlation coefficient (PCC).

## 2. OVERVIEW ON THE PCC

### 2.1. Meaning of the PCC

The Pearson correlation coefficient PCC (denoted $r_{xy}$) is a measure of the strength of the linear relationship between two variables x and y. It's defined by equation (1) as follows and it takes values in the closed interval [-1,+1].

$$PCC = r_{xy} = \frac{Cov(x,y)}{\sigma_x.\sigma_y} \tag{1}$$

Where, *Cov(x,y)* is the covariance between x and y, $\sigma_x$ the standard deviation of x and $\sigma_y$ the standard deviation of y.

The value PCC = +1 reflects a perfect positive correlation between x and y (based on the available data and observations), whereas the value PCC = 0 indicates that no correlation can be found between x and y. The value PCC = -1 reflects a perfect negative correlation between x and y [2].

Figure 1. shows the distribution form of the variable y as a function of the variable x for several cases:

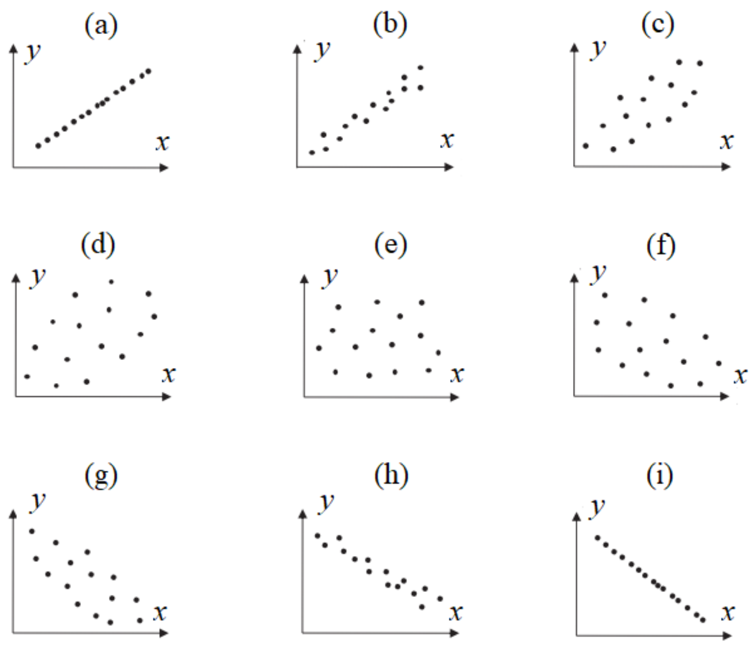


Figure 1. PCC value meaning.

Statistically speaking, we can distinguish the following cases in relation to the range of values of the PCC between x and y, showed in the previous figure:

a) PCC = 1, the variable y is perfectly correlated positively with the variable x.
b) 0.8 < PCC < 1, it testifies a strong positive correlation of the variable y with the variable x.
c) 0.4 < PCC < 0.8, it testifies a moderate positive correlation of the variable y with the variable x.
d) 0 < PCC < 0.4, it testifies a weak positive correlation of the variable y with the variable x.
e) PCC = 0, the variable y does not have any kind of linear correlation with the variable x.
f) - 0.4 < PCC < 0, it testifies a weak negative correlation of the variable y with the variable x.
g) - 0.8 < PCC < - 0.4, it testifies a moderate negative correlation of the variable y with the variable x.
h) - 1 < PCC < - 0.8, it testifies a strong negative correlation of the variable y with the variable x.
i) PCC = - 1, the variable y is perfectly correlated negatively with the variable x.

### 2.2. Context for using PCC as an assessment method

In this work, we apply the DCT to accomplish a lossy compression for ECG signals [3], the PCC and PRD were used together to measure the compression quality [4,5], and the CR to give the retained size of original ECG signal after compression. The following equations describe the above terms:

$$C(k) = \alpha(k) \sum_{n=0}^{N-1} x(n).\cos\left[\frac{2\pi}{N}\left(n+\frac{1}{2}\right)k\right] \quad (2)$$

Where, C(k) is the $k^{th}$ coefficient of the DCT in the frequency domain, and α(k) is the scaling factor expressed by:

$$\alpha(k) = \begin{cases} \sqrt{\frac{1}{N}} & for\ k = 0 \\ \sqrt{\frac{2}{N}} & for\ k \neq 0 \end{cases} \quad ; k = \{0, 1, \dots, N\text{-}1\}$$

$$CR = \frac{N_{org}}{N_{comp}} \quad (3)$$

$$PCC = 100 \times \frac{N\sum_{n=0}^{N-1} x(n)y(n) - \sum_{n=0}^{N-1} x(n)\sum_{n=0}^{N-1} y(n)}{\sqrt{[N\sum_{n=0}^{N-1} x(n)^2 - (\sum_{n=0}^{N-1} x(n))^2][N\sum_{n=0}^{N-1} y(n)^2 - (\sum_{n=0}^{N-1} y(n))^2]}} \quad (4)$$

$$PRD = 100 \times \sqrt{\frac{\sum_{n=0}^{N-1}[x(n)-y(n)]^2}{\sum_{n=0}^{N-1} x(n)^2}} \quad (5)$$

Where, x(n) is the original signal before compression and y(n) the reconstructed signal after compression, n is the sample's indice in the time domain; N and $N_{org}$ are the total number of bits in the original signal before compression, $N_{comp}$ is the number of bits in the compressed signal.

The PRD reflects the relative distance between the two ECG signals, before compression and after reconstruction; if they are the same, the PRD value is 0%. It is an objective criterion, but it cannot replace visual inspection or clinical evaluation, generally carried out by cardiologists [6].

It is established in [7] that if the PRD value is between 0% and 9%, the quality of the reconstructed signal is either "very good" or "good", whereas if the value is greater than 9%, its quality group cannot be approved. As we are strictly interested in good and very good reconstructions, we assume that the PRD value, as measured with (5), which is less than 9% does not guarantee results with certain qualities. This is the reason why we introduce the PCC parameter to deduce the range of values allowing for better reconstruction quality, without resorting to visual inspection of the waveforms before and after compression.

## 3. MATERIALS AND RESEARCH METHOD

ECG signals from the PTB arrhythmia database were used to evaluate the performance of the proposed lossy compression [8]. Both of normal and abnormal records for 20 subjects have been selected; these are the first records of each patient. thereby the first N samples ($N = N_{org} = 10000$) of the bipolar retained ECG signals DI, DII and DIII were used for test. It concerns four normal patients for healthy controls (Patients 104, 105, 116 and 121), four abnormal patients with myocardial infarction (Patients 1, 2, 3 and 4), four abnormal patients with dysrhythmia (Patients 168, 177, 187 and 218), four abnormal patients with bundle branch block (Patients 171, 175, 202 and 203) and four abnormal patients with myocardial hypertrophy (Patients 159, 210, 212 and 216).

The research method for this work is explained as follows: For each derivation DI, DII and DIII of the twenty patients, we have fixed four values of CR (2, 4, 8 and 16), and applied the DCT to switch from the time domain to the frequency domain, and keep the most energetic coefficients according to the defined CR; then we returned to the time domain thanks to the inverse DCT by setting the least energetic coefficients to zero, after that, we have calculated the corresponding PCC and PRD parameters using the time samples of the original signal x(n) and the signal y(n) reconstructed from the retained coefficients of the DCT. Finally, we have plotted the two signals x(n) and y(n) together, and compared the P, T waveforms and the QRS complexes to deduce the most suitable PCC value. Figure 2. shows the consecutive steps of the compression algorithm for deducing the best value of the PCC parameter.

| | |
|---|---|
| **Step 1:** | Choose the patient class (Healthy Controls: HC; Myocardial Infarction: MI; Dysrhythmia: DM; Bundle Branch Block: BBB; Myocardial Hypertrophy: MHT). |
| **Step 2:** | Choose the derivation ECG signal (DI; DII; DIII). |
| **Step 3:** | Fix the CR value (2; 4; 8; 16). |
| **Step 4:** | Apply the DCT (N = 10000 samples). |
| **Step 5:** | Retain the most energetic coefficients according to the defined CR (5000; 2500; 1250; 625). |
| **Step 6:** | Cancel the least energetic coefficients according to the defined CR (5000; 7500; 8750; 9375). |
| **Step 7:** | Apply the inverse DCT (N = 10000 samples). |
| **Step 8:** | Calculate the corresponding PCC and PRD parameters in time domain. |
| **Step 9:** | Compare the P, T waveforms and the QRS complexes in original and reconstructed ECG signals. |
| **Step 10:** | Conclusion about the suitable PCC. |

Figure 2. Compression algorithm steps applied to all ECG signals with various CR value.

The scripts translating the algorithm cited above were implemented using the language of technical computing MATLAB (R2016a) on a laptop with the following configuration: Windows 10 (64 bits), Intel Core i7 and 16 GB of RAM.

## 4. RESULTS AND DISCUSSION

For the three derivations of the ECG signals DI, DII and DIII of the twenty patients chosen, and with the four possible values of CR (2, 4, 8 and 16), we therefore processed a total of 240 possible cases. For each case, the PCC and PRD parameters were calculated according to equations (4) and (5), and the waveforms (P waves, T waves, QRS complexes) as well as the intervals (PR intervals, QT segments, ST intervals) were compared in order to locate areas of similarities and differences. In this section, we limited ourselves to expose some results obtained which confirms the adequate values of the PCC for which, the quality of the reconstructed signals after compression is preserved. Table 2. Shows the results obtained for a normal patient's class (Healthy Controls) denoted PTB104_HC, PTB105_HC, PTB116_HC and PTB121_HC.

With a minimum suitable value for PCC equal to 99.90%, the morphology of ECG signal before and after compression, is the same one as shown in Figure 3. In this example of results, the original ECG signal DII (PTB104_HC) needs 10000 samples for storage whereas the reconstructed one requires only 625 (CR=16).

In Figure 4, the shapes of the P, T waves and the QRS complexes for the original ECG signal DII and the reconstructed one are showed together for the minimum suitable value for PCC equal to 99.90% that allows a CR and a PRD equal to 16 and 4.26% respectively. There is a great similarity between waves and intervals before compression and after reconstruction.

Table 2. Results for normal patient's class.

| Patient | ECG Signal | Parameter (%) | Compression Ratio CR | | | |
|---|---|---|---|---|---|---|
| | | | CR = 2 | CR = 4 | CR = 8 | CR = 16 |
| PTB104_HC | DI | PRD | 1.19 | 2.58 | 3.74 | 13.58 |
| | | PCC | 99.99 | 99.96 | 99.93 | 99.07 |
| | DII | PRD | 0.54 | 1.21 | 2.38 | 4.26 |
| | | PCC | 99.99 | 99.99 | 99.97 | 99.90 |
| | DIII | PRD | 0.73 | 1.79 | 3.48 | 8.64 |
| | | PCC | 99.99 | 99.98 | 99.93 | 99.62 |
| PTB105_HC | DI | PRD | 1.33 | 2.88 | 4.55 | 11.87 |
| | | PCC | 99.99 | 99.95 | 99.89 | 99.29 |
| | DII | PRD | 1.08 | 2.33 | 5.11 | 11.42 |
| | | PCC | 99.99 | 99.97 | 99.86 | 99.34 |
| | DIII | PRD | 1.75 | 3.79 | 8.42 | 14.82 |
| | | PCC | 99.98 | 99.92 | 99.64 | 98.89 |
| PTB116_HC | DI | PRD | 1.28 | 2.56 | 4.75 | 10.47 |
| | | PCC | 99.99 | 99.96 | 99.88 | 99.45 |
| | DII | PRD | 1.00 | 2.59 | 5.20 | 16.23 |
| | | PCC | 99.99 | 99.96 | 99.86 | 98.67 |
| | DIII | PRD | 2.08 | 5.96 | 14.06 | 26.38 |
| | | PCC | 99.97 | 99.82 | 99.00 | 96.45 |
| PTB121_HC | DI | PRD | 0.95 | 1.89 | 2.92 | 10.72 |
| | | PCC | 99.99 | 99.98 | 99.95 | 99.42 |
| | DII | PRD | 1.32 | 3.14 | 7.14 | 21.41 |
| | | PCC | 99.99 | 99.95 | 99.74 | 97.68 |
| | DIII | PRD | 1.80 | 3.73 | 8.90 | 17.54 |
| | | PCC | 99.98 | 99.93 | 99.60 | 98.44 |

With another lower value for a PCC equal to 99.07% and with the same value of CR equal to 16, Figure 5, shows the shapes of the P, T waves and the QRS complexes for the original ECG signal DI (PTB104_HC) and the reconstructed one for a PRD equal to 13.58%. In this example of results, the morphology of reconstructed waves causes misdiagnosis.

For this class, 62.5% of cases show good compression quality with a PCC greater than or equal to 99.90%, on the other hand 37.50% produce poor reconstruction quality.

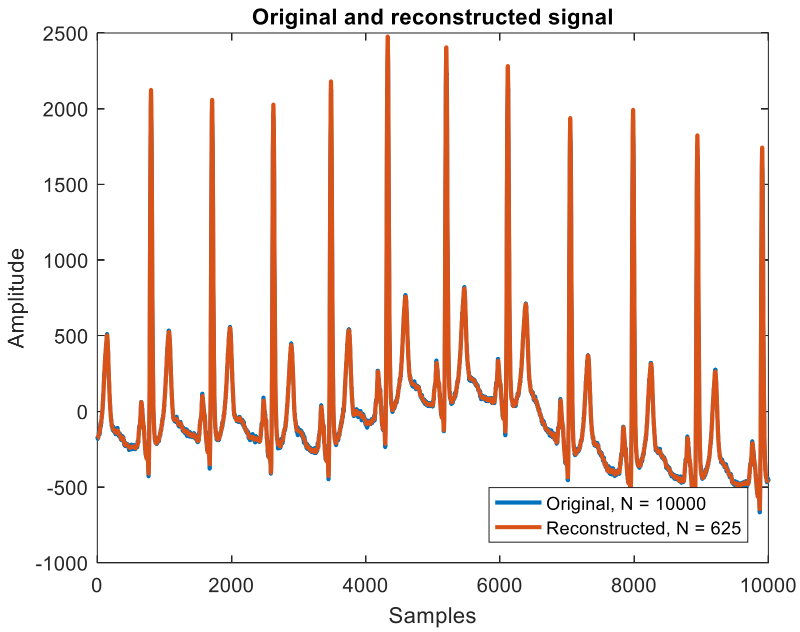


Figure 3. Original (Blue) and reconstructed (Red) ECG signal DII for patient PTB104_HC with CR=16, PRD=4.26% and PCC=99.90%.

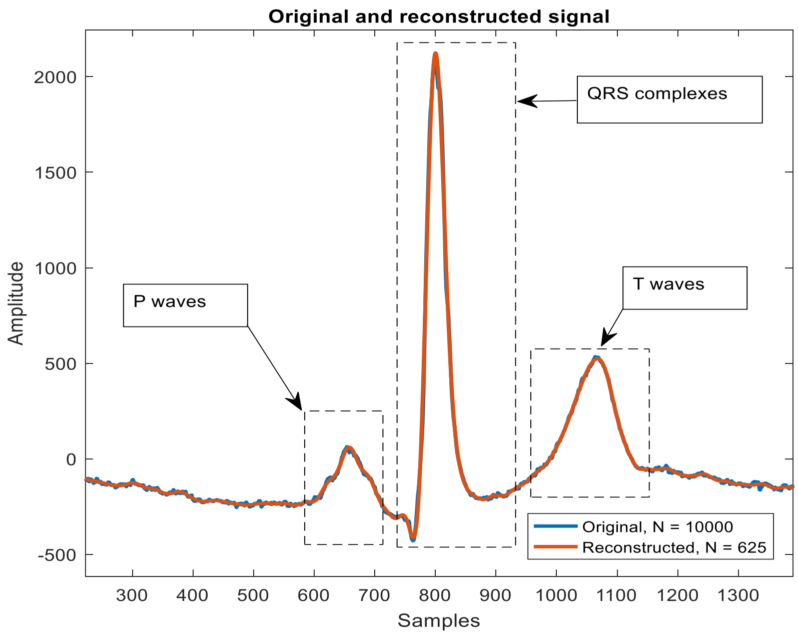


Figure 4. P, T waves and QRS complexes: Original (Blue) and reconstructed (Red) ECG signal DII for patient PTB104_HC with CR=16, PRD=4.26% and PCC=99.90%.

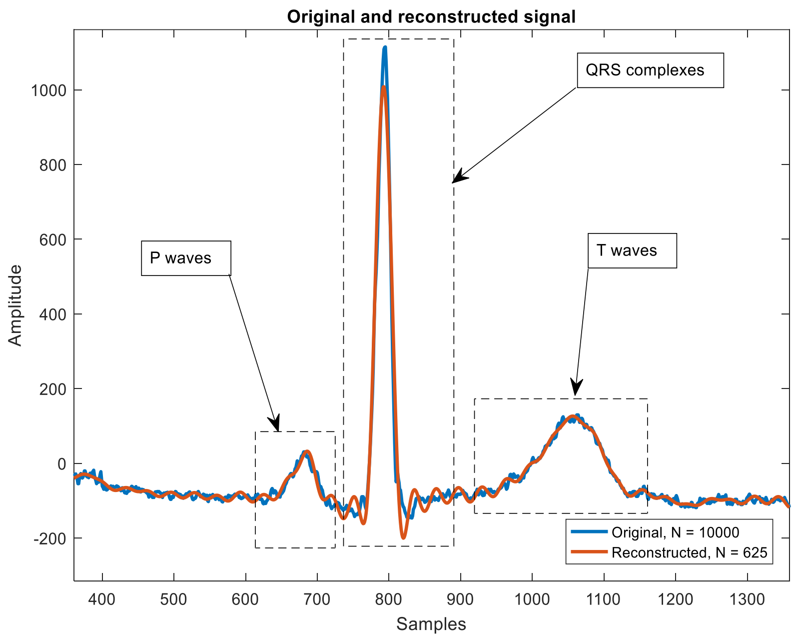


Figure 5. P, T waves and QRS complexes: Original (Blue) and reconstructed (Red) ECG signal DI for patient PTB104_HC with CR=16, PRD=13.58% and PCC=99.07%.

Table 3. shows the results obtained for myocardial infarction patient's class, denoted PTB1_MI, PTB2_MI, PTB3_MI and PTB4_MI.

Figure 6, illustrate together, the shapes of the P, T waves and the QRS complexes for the original ECG signal DIII (PTB1_MI) and the reconstructed one for the minimum suitable value for PCC equal to 99.90% that allows a CR and a PRD equal to 8 and 4.35% respectively. Similarity and resemblance between waves and intervals before compression and after reconstruction, appear clearly on this figure, except in a few areas, where there is the existence of high frequency noise which has no negative influence on medical diagnosis.

Table 3. Results for myocardial infarction patient's class.

| Patient | ECG Signal | Parameter (%) | Compression Ratio CR | | | |
|---|---|---|---|---|---|---|
| | | | CR = 2 | CR = 4 | CR = 8 | CR = 16 |
| PTB1_MI | DI | PRD | 4.39 | 7.66 | 11.12 | 15.57 |
| | | PCC | 99.90 | 99.70 | 99.37 | 98.78 |
| | DII | PRD | 2.10 | 3.63 | 6.97 | 16.57 |
| | | PCC | 99.97 | 99.93 | 99.75 | 98.61 |
| | DIII | PRD | 1.58 | 2.77 | 4.35 | 10.64 |
| | | PCC | 99.98 | 99.96 | 99.90 | 99.43 |
| PTB2_MI | DI | PRD | 3.85 | 8.01 | 11.58 | 14.55 |
| | | PCC | 99.92 | 99.67 | 99.32 | 98.93 |
| | DII | PRD | 1.62 | 3.91 | 6.04 | 8.02 |
| | | PCC | 99.98 | 99.92 | 99.81 | 99.67 |
| | DIII | PRD | 1.47 | 2.87 | 4.08 | 4.99 |
| | | PCC | 99.98 | 99.95 | 99.91 | 99.87 |
| PTB3_MI | DI | PRD | 4.04 | 7.06 | 8.78 | 12.79 |
| | | PCC | 99.91 | 99.75 | 99.61 | 99.17 |
| | DII | PRD | 2.87 | 5.32 | 6.84 | 11.01 |
| | | PCC | 99.95 | 99.85 | 99.76 | 99.39 |
| | DIII | PRD | 2.26 | 3.88 | 4.97 | 11.14 |
| | | PCC | 99.97 | 99.92 | 99.87 | 99.37 |
| PTB4_MI | DI | PRD | 1.81 | 3.57 | 5.35 | 12.15 |
| | | PCC | 99.98 | 99.93 | 99.85 | 99.25 |
| | DII | PRD | 2.04 | 4.41 | 6.31 | 12.81 |
| | | PCC | 99.97 | 99.90 | 99.80 | 99.17 |
| | DIII | PRD | 2.45 | 5.61 | 9.03 | 22.03 |
| | | PCC | 99.96 | 99.84 | 99.59 | 97.54 |

For this class, only 43.75% of cases show good compression quality with a PCC greater than or equal to 99.90%, on the other hand 56.25%, more than half, produces bad quality of reconstruction.

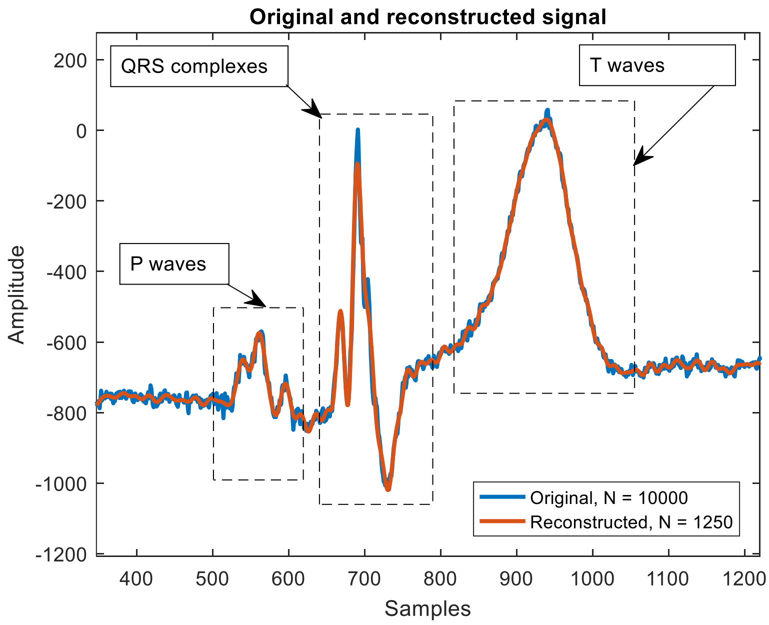


Figure 6. P, T waves and QRS complexes: Original (Blue) and reconstructed (Red) ECG signal DIII for patient PTB1_MI with CR=8, PRD=4.35% and PCC=99.90%.

Table 4. shows the results obtained for myocardial hypertrophy patient's class, denoted PTB159_MHT, PTB210_MHT, PTB212_MHT and PTB216_MHT.

Table 4. Results for myocardial hypertrophy patient's class.

| Patient | ECG Signal | Parameter (%) | Compression Ratio CR | | | |
|---|---|---|---|---|---|---|
| | | | CR = 2 | CR = 4 | CR = 8 | CR = 16 |
| PTB159_MHT | DI | PRD | 1.28 | 2.52 | 3.77 | 9.49 |
| | | PCC | 99.99 | 99.96 | 99.92 | 99.54 |
| | DII | PRD | 2.05 | 4.51 | 7.41 | 18.00 |
| | | PCC | 99.97 | 99.89 | 99.72 | 98.36 |
| | DIII | PRD | 2.47 | 5.19 | 8.79 | 17.83 |
| | | PCC | 99.96 | 99.86 | 99.61 | 98.39 |
| PTB210_MHT | DI | PRD | 2.06 | 3.34 | 4.42 | 6.66 |
| | | PCC | 99.97 | 99.94 | 99.90 | 99.77 |
| | DII | PRD | 0.80 | 1.42 | 2.78 | 5.36 |
| | | PCC | 99.99 | 99.98 | 99.96 | 99.85 |
| | DIII | PRD | 1.11 | 1.87 | 4.75 | 7.15 |
| | | PCC | 99.99 | 99.98 | 99.88 | 99.74 |
| PTB212_MHT | DI | PRD | 0.58 | 1.42 | 2.26 | 11.06 |
| | | PCC | 99.99 | 99.98 | 99.97 | 99.38 |
| | DII | PRD | 0.68 | 1.49 | 4.53 | 7.39 |
| | | PCC | 99.99 | 99.98 | 99.89 | 99.72 |
| | DIII | PRD | 1.09 | 4.08 | 8.62 | 21.41 |
| | | PCC | 99.99 | 99.91 | 99.62 | 97.68 |
| PTB216_MHT | DI | PRD | 0.77 | 1.44 | 2.26 | 5.23 |
| | | PCC | 99.99 | 99.98 | 99.97 | 99.86 |
| | DII | PRD | 0.72 | 1.51 | 3.43 | 6.46 |
| | | PCC | 99.99 | 99.98 | 99.94 | 99.79 |
| | DIII | PRD | 0.85 | 1.93 | 4.44 | 7.63 |
| | | PCC | 99.99 | 99.98 | 99.90 | 99.70 |

Figure 7, show together, the shapes of the QRS complexes and the P, T waves for the original ECG signal DIII (PTB210_MHT) and the reconstructed for the minimum suitable value for PCC equal to 99.88% that allows a CR and a PRD equal to 8 and 4.75% respectively. On this figure, appear clearly the full similarity and resemblance between waves and intervals before compression and after reconstruction.

For this class 68.75%, which represents most cases, shows a good compression quality with a PCC greater than or equal to 99.88%, on the other hand 31.25%, produce poor reconstruction quality.

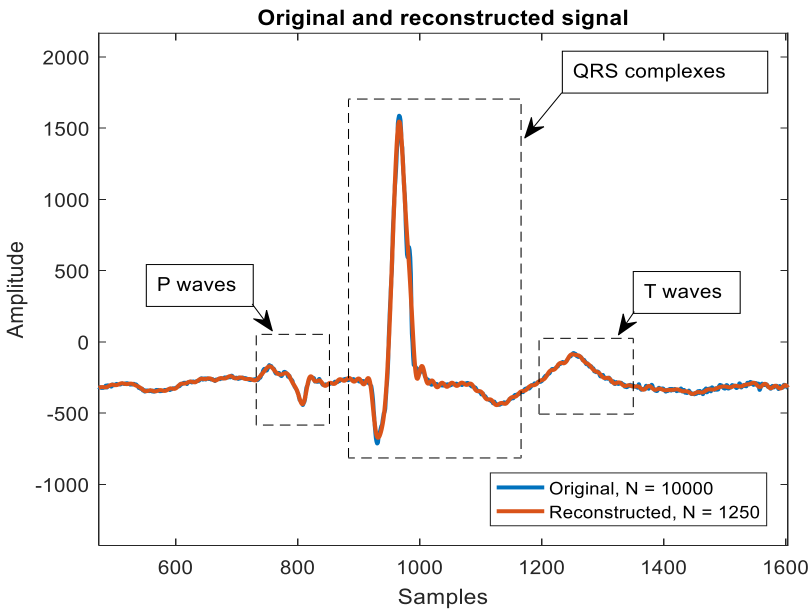


Figure 7. P, T waves and QRS complexes: Original (Blue) and reconstructed (Red) ECG signal DIII for patient PTB210_MHT with CR=8, PRD=4.75% and PCC=99.88%.

Table 5. shows the results obtained for dysrhythmia patient's class, denoted PTB168_DM, PTB177_DM, PTB187_DM and PTB218_DM.

Table 5. Results for dysrhythmia patient's class.

| Patient | ECG Signal | Parameter (%) | Compression Ratio CR | | | |
|---|---|---|---|---|---|---|
| | | | CR = 2 | CR = 4 | CR = 8 | CR = 16 |
| PTB168_DM | DI | PRD | 3.44 | 5.92 | 7.78 | 17.47 |
| | | PCC | 99.94 | 99.82 | 99.69 | 98.46 |
| | DII | PRD | 1.85 | 3.06 | 4.63 | 7.91 |
| | | PCC | 99.98 | 99.95 | 99.89 | 99.68 |
| | DIII | PRD | 2.92 | 5.30 | 9.51 | 14.30 |
| | | PCC | 99.95 | 99.85 | 99.54 | 98.97 |
| PTB177_DM | DI | PRD | 2.29 | 4.21 | 7.16 | 11.99 |
| | | PCC | 99.97 | 99.91 | 99.74 | 99.27 |
| | DII | PRD | 0.73 | 1.50 | 3.15 | 6.70 |
| | | PCC | 99.99 | 99.98 | 99.95 | 99.77 |
| | DIII | PRD | 1.06 | 2.35 | 6.39 | 11.54 |
| | | PCC | 99.99 | 99.97 | 99.79 | 99.33 |
| PTB187_DM | DI | PRD | 1.13 | 2.12 | 3.44 | 7.50 |
| | | PCC | 99.99 | 99.97 | 99.94 | 99.71 |
| | DII | PRD | 1.05 | 2.39 | 4.14 | 12.73 |
| | | PCC | 99.99 | 99.97 | 99.91 | 99.18 |
| | DIII | PRD | 1.53 | 2.97 | 5.04 | 20.35 |
| | | PCC | 99.98 | 99.95 | 99.87 | 97.90 |
| PTB218_DM | DI | PRD | 1.22 | 2.30 | 3.15 | 3.97 |
| | | PCC | 99.99 | 99.97 | 99.95 | 99.92 |
| | DII | PRD | 0.49 | 0.91 | 1.50 | 2.49 |
| | | PCC | 99.99 | 99.99 | 99.98 | 99.97 |
| | DIII | PRD | 0.75 | 1.37 | 2.01 | 2.77 |
| | | PCC | 99.99 | 99.99 | 99.97 | 99.96 |

In Figure 8, the shapes of the P, T waves and the QRS complexes for the original ECG signal DII (PTB168_DM) and the reconstructed one are showed together for the minimum suitable value for PCC equal to 99.89% that allows a CR and a PRD equal to 8 and 4.63% respectively. There is a full similarity between waves and intervals before compression and after reconstruction.

For this class 66.67%, more than half of the cases, show good compression quality with a PCC greater than or equal to 99.89%, on the other hand 33.33%, produce poor reconstruction quality.

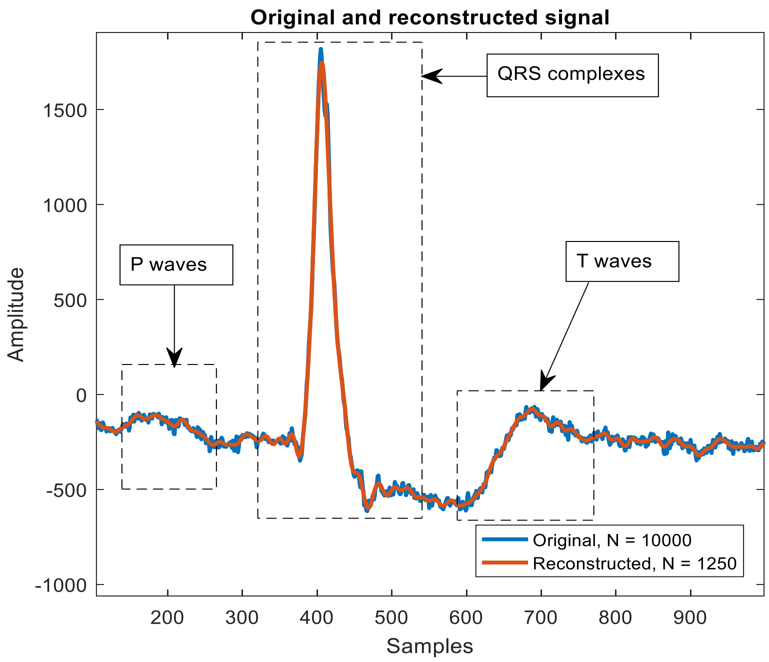


Figure 8. P, T waves and QRS complexes: Original (Blue) and reconstructed (Red) ECG signal DII for patient PTB168_DM with CR=8, PRD=4.63% and PCC=99.89%.

Table 6. shows the results obtained for bundle branch block patient's class, denoted PTB171_BBB, PTB175_BBB, PTB202_BBB and PTB203_BBB.

Table 6. Results for bundle branch block patient's class.

| Patient | ECG Signal | Parameter (%) | Compression Ratio CR | | | |
|---|---|---|---|---|---|---|
| | | | CR = 2 | CR = 4 | CR = 8 | CR = 16 |
| PTB171_BBB | DI | PRD | 1.15 | 2.18 | 3.51 | 6.07 |
| | | PCC | 99.99 | 99.97 | 99.93 | 99.81 |
| | DII | PRD | 2.50 | 5.43 | 7.11 | 13.33 |
| | | PCC | 99.96 | 99.85 | 99.74 | 99.10 |
| | DIII | PRD | 2.40 | 4.90 | 7.44 | 12.60 |
| | | PCC | 99.97 | 99.87 | 99.72 | 99.20 |
| PTB175_BBB | DI | PRD | 0.59 | 1.05 | 1.54 | 4.18 |
| | | PCC | 99.99 | 99.99 | 99.98 | 99.91 |
| | DII | PRD | 1.00 | 1.77 | 2.69 | 8.21 |
| | | PCC | 99.99 | 99.98 | 99.96 | 99.66 |
| | DIII | PRD | 1.85 | 3.37 | 5.57 | 12.03 |
| | | PCC | 99.98 | 99.94 | 99.84 | 99.27 |
| PTB202_BBB | DI | PRD | 0.74 | 1.69 | 3.18 | 15.20 |
| | | PCC | 99.99 | 99.98 | 99.94 | 98.83 |
| | DII | PRD | 0.60 | 1.38 | 3.73 | 21.64 |
| | | PCC | 99.99 | 99.99 | 99.93 | 97.62 |
| | DIII | PRD | 1.20 | 3.10 | 7.83 | 17.83 |
| | | PCC | 99.99 | 99.95 | 99.69 | 98.39 |
| PTB203_BBB | DI | PRD | 1.55 | 2.95 | 4.25 | 7.13 |
| | | PCC | 99.98 | 99.95 | 99.90 | 99.74 |
| | DII | PRD | 0.60 | 1.10 | 2.78 | 10.64 |
| | | PCC | 99.99 | 99.99 | 99.96 | 99.43 |
| | DIII | PRD | 1.28 | 2.57 | 5.06 | 18.94 |
| | | PCC | 99.99 | 99.96 | 99.87 | 98.18 |

The shapes of the QRS complexes and the P, T waves for the original ECG signal DI (PTB203_BBB) and the reconstructed are drawed together in Figure 9, for the minimum suitable value for PCC equal to 99.90% that allows a CR and a PRD equal to 8 and 4.25% respectively. On this figure, appear clearly the full similarity and resemblance between waves and intervals before compression and after reconstruction.

For this class 62.5%, more than half of the cases, show good compression quality with a PCC greater than or equal to 99.90%, on the other hand 37.5%, produce poor reconstruction quality.

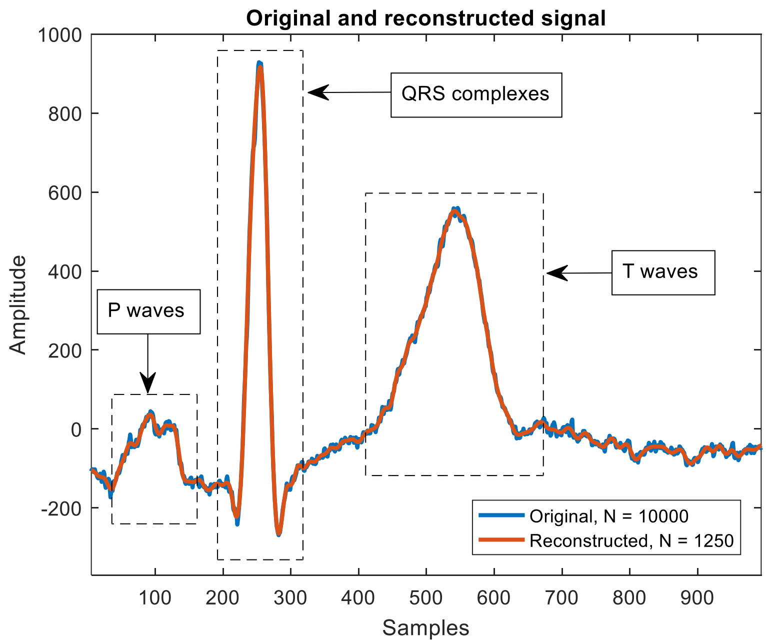


Figure 9. P, T waves and QRS complexes: Original (Blue) and reconstructed (Red) ECG signal DI for patient PTB203_BBB with CR=8, PRD=4.25% and PCC=99.90%.

By calculating and analyzing the average PCC value of leads DI, DII and DIII for each type of pathology and each CR value reported in Table 7, we can confirm that the PCC value which exceeds 99.90%

guarantees a CR of 4 or more, for most of the pathological cases with the exception of class MI. However, for class BBB, a CR value around 8 can be achieved.

Table 7. Average PCC value.

| Pathology class | Derivation | Average PCC value (%) | | | |
|---|---|---|---|---|---|
| | | CR = 2 | CR = 4 | CR = 8 | CR = 16 |
| HC | DI | 99.99 | 99.96 | 99.91 | 99.30 |
| | DII | 99.99 | 99.96 | 99.85 | 98.89 |
| | DIII | 99.98 | 99.91 | 99.54 | 98.35 |
| MI | DI | 99.92 | 99.62 | 99.53 | 99.03 |
| | DII | 99.96 | 99.90 | 99.78 | 99.21 |
| | DIII | 99.97 | 99.81 | 99.81 | 99.05 |
| MHT | DI | 99.98 | 99.96 | 99.94 | 99.63 |
| | DII | 99.98 | 99.95 | 99.87 | 99.43 |
| | DIII | 99.98 | 99.93 | 99.75 | 98.87 |
| DM | DI | 99.97 | 99.91 | 99.83 | 99.34 |
| | DII | 99.98 | 99.97 | 99.93 | 99.65 |
| | DIII | 99.97 | 99.94 | 99.79 | 99.04 |
| BBB | DI | 99.98 | 99.97 | 99.93 | 99.57 |
| | DII | 99.98 | 99.93 | 99.90 | 98.95 |
| | DIII | 99.98 | 99.93 | 99.78 | 98.76 |

These results encourage us to set as a condition the PCC equal to 99.90%, and evaluate, at the same time, the CR and the shape of the P waves, T waves and QRS complexes for several lossy compression techniques other than DCT such as SPIHT (Set Partitioning In Herarchical Tree), DWT ( Discrete Wavelet Transform) and HC (Huffman Coding).

## 5. CONCLUSION

Based on the obtained numerical results and the comparison of the shape of waveforms, especially the P waves, T waves and the QRS complexes of the processed ECG signals before compression and after reconstruction, we can confirm that the range of values of the PCC parameter which ensures compression with better reconstruction quality is between 99.90% and 100% . The CR values, which exceeded 4 for most cases and which sometimes reached 16, were not the same, whether for the different pathologies or the different derivations, but demonstrate the advantage of using PCC. In future work, we will automate the compression process by first setting the PCC at the minimum value around 99.90%, and proceed to process the derivation concerned to ensure good reconstruction quality whatever the nature of the pathology. This will produce remarkable CR values, but will not be the same for different leads of the ECG signals.

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