

# Recovering Electrocardiogram Missing Samples in Wireless Transmission

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## Abstract

*Considering the emergence of telemedicine applications, different links such as fixed access network (PSTN), mobile access network (GSM/GPRS and future UMTS) or satellite interfacing (DVB-RCS technology) are involved in e-health applications. These are liable to induce errors and/or missing packets on the received data. Therefore the recovering of missing samples for biomedical signals is of great interest.*

*This paper proposes a reconstruction method for ECG signals which is a combination of a left-sided and right-sided autoregressive (AR) model, and the well-known Gerchberg-Papoulis (GP) method. The proposed interpolation algorithm takes into account the samples before and after the missing ones to estimate a forward and a backward AR model. These estimates are used as an initialization of the original GP method. Results show that this interpolation method represents a really suitable technique to ECG reconstruction in a possible corrupted transmission.*

## 1. Introduction

In recent years, e-health applications have considerably increased. Among these applications, the development of sophisticated wearable sensors has permitted to consider new forms of telemedicine, especially for telemonitoring. In this context, the project OURSES has been proposed by the French competitiveness cluster named "Aerospace Valley" (<http://www.aerospace-valley.com/en/>). This project proposes the implementation of a health monitoring system of elderly people using a satellite link. The choice of the satellite as a communication channel is based on the fact that there still exists regions, especially in mountains, which can be considered *isolated* from a telecommunication point of view, i.e. in these areas, no cellular phone coverage nor high bit rate connections (e.g. ADSL) are available. The project OURSES proposes to monitor vital signs of elderly people living alone in their homes or in specialized structures, in these

isolated areas. Therefore, each "patient" will wear a sensor allowing the recording of one ECG lead. This sensor is connected to a PDA (Personal Digital Assistant), also worn by the patient, through a radio link. The PDA is able to send the received ECG to a computer, through a Wi-Fi link. The computer is located in the house of the patient, allowing the patient to walk around and to be monitored, while staying at a Wi-Fi link distance from the computer. The computer is in charge of analysing the received ECG, in real-time, to detect possible anomalies in these signals. If a possible cardiac problem is detected, an alarm is raised and sent to a chosen corresponding physician. This physician, who usually lives up to 40 kms from the patient in these isolated areas, can access to a web server from his office, where all recorded ECG signals can be consulted, through a satellite connection. In this way, the physician can analyse the different received ECG signals and if the raised alarm is confirmed, he can take the necessary decision (contact a nurse or an emergency unit).

Considering that a physician clear diagnostic needs clean and complete ECG signals, possible losses in the transmission via satellite become critic. The major problem in the satellite channel is that the Transmission Control Protocol (TCP), designed in principle for the wired networks, is unable to distinguish between packet losses due to transmission errors and packet losses due to congestion. TCP supposes that all packets losses are congestion-related and reacts by reducing the sending rate, even though this is necessary only in the latter case. This will become a major problem if streamed data are transmitted (e.g. an ECG signal). If a file transmission is considered periodically, mechanisms like the Automatic Repeat Request (ARQ) and Forward Error Control (FEC), taking into account the possible delays, are robust enough for avoiding possible losses.

Due to possible losses in the satellite transmission, this paper proposes a method for reconstruction of missing samples of ECG signals. This method is based on a modification of the initialization of the Gerchberg-Papoulis (GP) algorithm. The proposed method uses a left-sided and right-sided AR models for the

reconstruction of the missing samples. This prior reconstruction is the initialization in the GP method. The GP algorithm and the proposed modification are detailed in section 3. Performances of this method and of the original one are compared in section 4. Conclusion is reported in the last section.

## 2. Problem formulation

In our telemonitoring application, lost packets in a satellite transmission result in missing samples in ECG signals, as illustrated in figure 1.

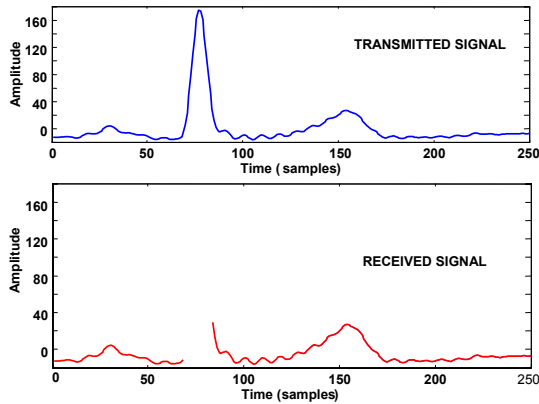


Figure 1. Lost samples in an ECG signal transmission.

Reconstruction of missing samples in ECG signals has already been considered, especially using one of the most popular algorithms which is the Gerchberg-Papoulis (GP) one [1-4]. Another method, based on AR modelling has also been presented [9]. In the present paper, interaction between these two ideas is considered and a combination of both algorithms is proposed.

## 3. Reconstruction methods

Within the frame of missing sample recovering, the GP method [1-4] is one of the most popular. It interpolates missing samples considering that the signal is band-limited. Based on this fact, the method proposes iterations between the time and frequency domains for the reconstruction of the missing samples, as follows:

**Default initialization:** zero values for missing samples.

**Iterations:**

- Signal is transformed using the Fast Fourier Transform (FFT).
- In the frequency domain, the transformed signal is hard-limited in band (filtering).
- The signal is reconstructed in the time domain using the inverse FFT.
- Finally, the signal used for the next iteration is the

original one except that the missing sample part is replaced by the one issued from the previous iteration.

Iterations are done to obtain a good signal reconstruction.

Based on [5-8] designed for audio signal restoration, another ECG missing sample reconstruction has been proposed [9]. This algorithm uses a forward and a backward model around the missing part. This modeling is a classic AR model, defined by

$$\hat{x}(n) = -\sum_{k=1}^p a_k x(n-k) + e(n) \quad (1)$$

where  $x(n)$  is the original signal,  $p$  is the model order,  $a_k$  are the linear prediction coefficients (LPC) and  $e(n)$  is the model error or the linear prediction error (LPE).

Let us consider an ECG signal which contains a missing sample sequence of  $M$  samples between two segments of  $N$  samples each, with  $N > M$ . The proposed algorithm for a reconstruction of the ECG missing samples consists of the next steps:

1. Estimation of the AR model of a given order  $p$  for the segment of  $N$  samples **before** the missing part.
2. Computation of the model excitation  $e(n)$  by inverse filtering.
3. Extension of this excitation by addition of first  $M$  samples of the time-reversed version.
4. Filtering of this extended version of the excitation by the AR model. The filtered signal resulting corresponds to the forward signal reconstruction.
5. Steps 1 to 4 are redone in order to obtain the interpolation in the backward way. For this, consider the  $N$  samples placed immediately **after** the missing part.
6. The forward and the backward models are affected by a cross-fading window to reduce the interference in the middle of the missing part.

The window used in the cross-fading is defined by [7]

$$w(n) = \begin{cases} 1 - \frac{1}{2}(2u(n))^\alpha, & u(n) \leq \frac{1}{2} \\ \frac{1}{2}(2 - 2u(n))^\alpha, & u(n) > \frac{1}{2} \end{cases} \quad (2)$$

where  $u(n) = (n - n_s) / (n_e - n_s)$ , with  $n_s$  and  $n_e$  being, respectively, the indices of the beginning and the end of the missing sample part. The parameter  $\alpha$  modifies the window's roll-off.

This procedure is illustrated in figure 2.

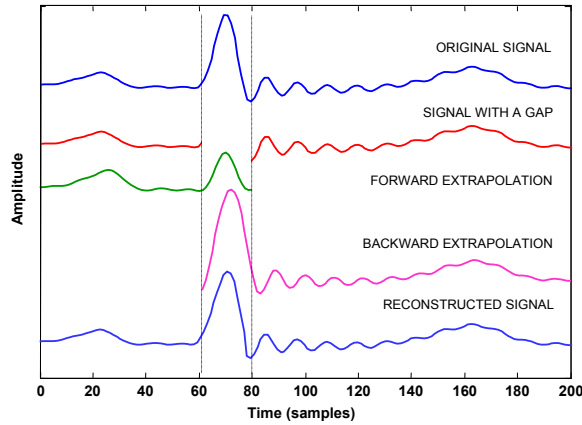


Figure 2. ECG missing sample recovering based on forward and backward AR modeling.

In this paper, we propose to combine both kinds of recovering: PG and AR methods, by using the AR recovering as an initialization of the PG algorithm. The complete chain is shown in figure 3.

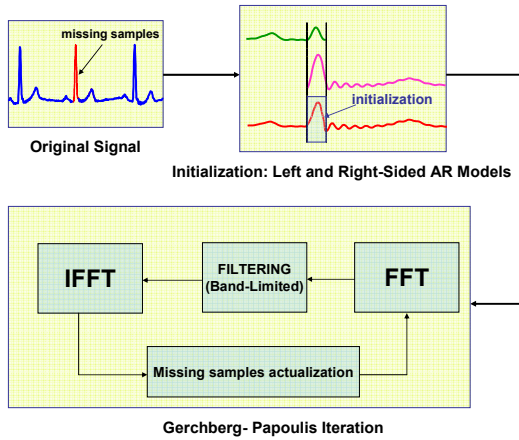


Figure 3. The proposed missing sample recovering method.

#### 4. Results

At the time of the paper publication, tests on real patients are not finalized in the OURSES project. Therefore, the proposed method was tested, on the MIT Arrhythmia Database [10], especially in ECG records 100, 119 and 200. A large number of missing sample part (3700 “gaps”) of length going from 5 to 30 samples were generated in a random way over each ECG record.

Once missing samples are identified, an analyzing window is established to perform the first reconstruction based on the left-sided and right-sided AR models. This analyzing window has a length  $N$ , where  $N$  is set to 250 samples (around one second). This corresponds to a time

slot where ECG signals can be considered to be stationary.

The AR model order (forward and backward) is chosen equal to  $p=50$ , based on an analysis of the LPE. By plotting the LPE as a function of the model order, one can observe that the LPE is decreasing but for  $p>50$ , it does not decrease significantly anymore. Note that a classical criterion of modeling order such as MDL or AIC [10] would provide a lower model order. However, since we are not interested in spectral analysis here but only in deriving a liable temporal model of the signal, an overestimation of the model order is preferable. The parameter  $\alpha$  (cross-fading window’s roll-off) is set to 2. The used method to estimate the LPC is the classic Burg method [10].

An objective measure based on a **local** SNR (Signal to Noise reconstruction Ratio) was used to assess the method performance. This measure is defined by

$$SNR = 10 \log \left( \frac{\sigma_{xgap}^2}{\sigma_{(x-\hat{x})gap}^2} \right) \text{ in dB} \quad (3)$$

where  $\sigma_{xgap}^2$  represents the variance of the original signal in the missing part and  $\sigma_{(x-\hat{x})gap}^2$  represents the variance of the reconstruction error also restricted in the missing part. The number of iterations for the GP method was empirically set to 500. After this value, none improvement in the reconstruction is encountered.

In what follows, the three methods are compared: the classical GP algorithm, the AR-based one [9] and the present proposed algorithm (GP method with AR initialization, named GP-AR). Resulting local SNR in dB are plotted as a function of the missing samples length. Figures 4, 5 and 6 show these results on the ECG records 100, 119 and 200 respectively.

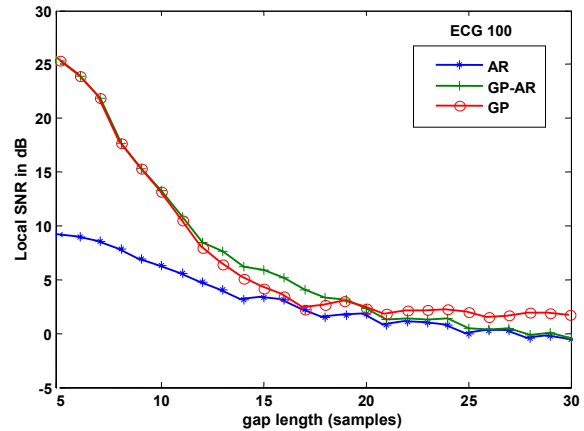


Figure 4. Performance of three different methods for the missing samples reconstruction of the ECG record 100.

## 5. Discussion and conclusion

Results show that the performance of the AR-based recovering [9] is sometimes better than the GP algorithm (in the case of gaps of more than 13 samples for records 119 and 200) but is sometimes worse in the case of record 100 for example. However, combining both approaches, the present proposed method (GP-AR) gives the best results in all cases. Indeed, it allows a gain from 2 to 8 dB (depending on the missing samples length) over the two other methods.

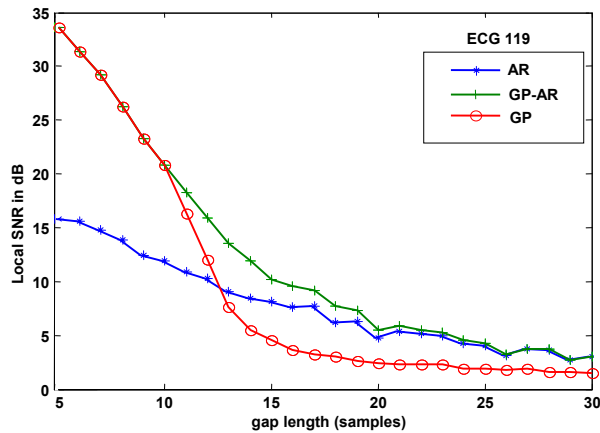


Figure 5. Performance of three different methods for the missing samples reconstruction of the ECG record 119.

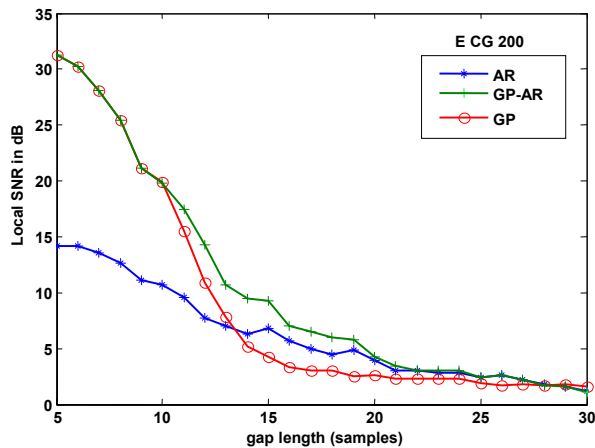


Figure 6. Performance of three different methods for the missing samples reconstruction of the ECG record 200.

In figure 7, a reconstruction example is shown. In this case, only a segment of 15 missing samples of the ECG record 200 is considered. Best reconstruction of this complex QRS is obtained with the proposed GP-AR method.

The local SNR measure, in order to validate the

reconstruction, must be coupled with the physician criterion to assure an acceptable reconstruction.

Results show that this interpolation method represents a really suitable technique to ECG signal reconstruction in a possible corrupted transmission.

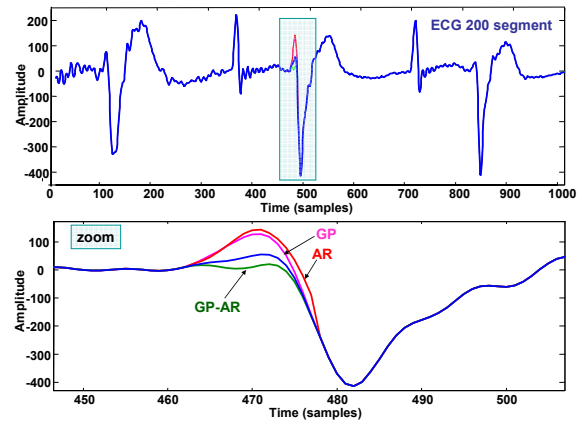


Figure 7. Example of an ECG reconstruction.

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