IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Traitement du Signal
Vol. 39, No. 4, August, 2022, pp. 1357-1362
Journal homepage: http://iieta.org/journals/ts

Medical Signal Processing via Digital Filter and Transmission Reception Using Cognitive Radio Technology

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https://doi.org/10.18280/ts.390429

Received: 15 June 2022
Accepted: 3 August 2022

Keywords:
cognitive radio, digital filter, electro cardiogram, noise cancellation

ABSTRACT

This research paper provides a viable solution for processing noise affected Electrocardiogram (ECG) signal via digital filter and transmission of ECG signal and reception via cognitive radio (CR) technology. Health assessment signals such as ECG signal, Electroencephalogram (EEG) signal, Electromyogram (EMG) signal are vital for diagnosis and rehabilitation of human welfare among which ECG attains prime importance due to its information on heart functioning. However, electrocardiogram signals are prone to addition of noise such as power line noise 50 Hz mainly due to improper shielding which can lead to wrong interpretation, incorrect diagnosis and at times will eventually lead to loss of human life. On combining signal processing into medical applications misconceptions can be eliminated and diagnosis can be done effectively through a designed digital filter. Effect of noise can be cancelled in an ECG signal and by using cognitive radio technology ECG information can be transmitted to a medical physician mobile terminal for remedial measures relating to medical treatment. Simulation results are shown in matrix laboratory (MATLAB) for cancelling noise in an ECG signal having noise using a digital filter which is designed represented by its transfer function. Also, ECG signal is transmitted and received in a CR system where the metric of probability of error is obtained which can be useful for signal processing fraternity.

1. INTRODUCTION

Cognitive radio technology has nowadays found to be of importance in medicinal field for human health in present day world [1, 2]. Signals such as 1-Dimensional signal namely a speech signal, 2-Dimensional signal like that of an image signal and 3-Dimensional signal as that of a video signal can be transmitted and received effectively through proper spectrum utilization using cognitive radio [3]. Cognitive radio has sensing capability to locate the vacant spectrum hole or spectrum band where an unlicensed user can acquire the licensed spectrum for information data transmission and reception. Such cognitive radio can be surfaced to have profound applications in emergency situations, disaster management where among that medicinal healthcare is deemed to be vital. In healthcare transmission of medical signals and reception is very essential which is to be done in an uninterrupted manner and send reports to the medical physician so that timely diagnosis can be done. Various medical signals such as ECG, EEG and EMG are vital for diagnosis in healthcare. However, electrocardiogram gets corrupted by noise where noise cancellation [4, 5] is required. Further, artifacts [6] affect ECG signals which are signals with larger amplitude which occur due to placement of electrodes, frequent changing of electrodes, electrical disturbances, physical other body part contacts of patients. Also, noise such as power line noise, interference and other electrical disturbances are also other disturbing signals which can lead to wrong diagnosis for a physician.

By suitable design of digital filter for power line noise such as 50 Hz or 60 Hz depending on the frequency, artifacts can be removed. A suitable digital filter can be designed and the corrupted ECG signal can be passed through the digital filter [6-9] to recover the desired ECG signal. Several research papers have been presented and surveyed. But in this paper it is proposed to cancel the noise in the ECG signal through a noise cancellation filter [10-12]. Normally noise gets acquired during recording of ECG signal probably 50 Hz power line noise. The noise cancelled [13-17] signal is then transmitted as data to the medical physician mobile terminal through cognitive radio technology which is an intelligent form of communication. The noise considered in this research paper can also be considered as narrowband interference (NBI) [18]. Narrowband interference is an interference where it can be considered to be a signal which has very less bandwidth. It is an analog signal which has continuous time and continuous amplitude resembling to be a sharp spike. Such NBI is deemed to be unwanted and it needs to removed when acquired during signal transmission. NBI can be removed with a narrowband notch filter and not a wideband filter as in the study [19]. The outline of this paper is that section I gives introduction, section II presents ECG signal processing and noise cancellation, section III presents cognitive radio ECG signal results and discussions and section IV gives conclusions to the paper.

2. ELECTROCARDIOGRAM SIGNAL PROCESSING AND NOISE CANCELLATION

Electrocardiogram signal [4, 5] recorded by having electrodes positioned at places exterior to the human body can exhibit normal readings or abnormal readings based on the surroundings. Normal readings provide accurate analysis for a medical physician to have proper diagnosis. Abnormal readings can also provide better analysis for medical diagnosis but at the same time wrong diagnosis can be done due to improper readings obtained. The values obtained in ECG can be improper but can also be due to certain issues in the ECG readings which may due to artifacts, interferences and noise. ECG readings have to be free from such aforementioned issues. The ECG signal in mathematical form [20] is given as

$$y(n) = e_{cg}(n) \tag{1}$$

Figure 1 shows ECG signal generated for 1500 samples for 2 beats/sec considered with a sampling frequency of 1 kHz. An ECG signal is represented by PQRS wave for a particular duration of time in observation. P waves represent atrial depolarization where it always precedes a QRS complex. The PR interval is the start of P wave to start of R wave where it represents the time taken for electrical activity between the atria and ventricles.

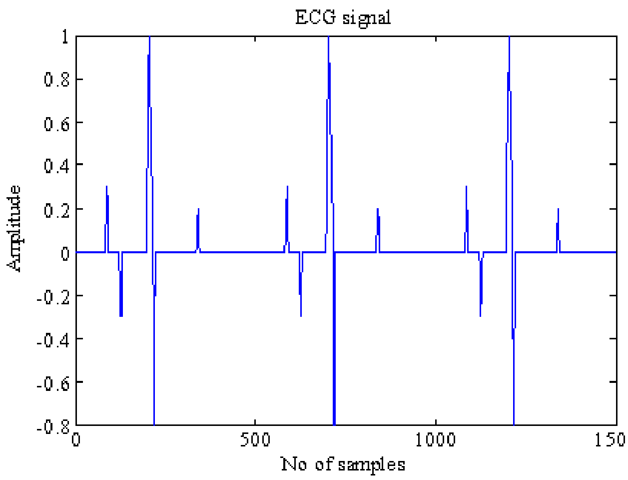

Figure 1. Electrocardiogram signal

The QRS complex represents depolarization of ventricles. ST segment represents the start of S wave and finishes at the start of T wave and it is an electrical line representing time between depolarization and repolarization of ventricles obviously contraction. The T wave is ventricular repolarization and it is the small wave after QRS complex. Though in Figure 1 an ECG signal is shown the initial spike is the P wave followed by a small spike and longer spike representing QRS complex and afterwards a T wave forming the ST signal [4-8]. If such an ECG signal is corrupted by 50 Hz noise, it can be represented by Figure 2. The 50 Hz noise can also be considered as narrowband interference [19, 20] is generated by a cosinusoidal signal represented by

$$p_{50}(n) = \cos(\pi 0.05n) \tag{2}$$

where, 0.05 rad/sec represents the digital frequency for an analog frequency of 50 Hz and a sampling frequency of 1 kHz. This 50 Hz noise is found to corrupt the ECG signal at the digital frequency of 0.05 rad/sec. The noisy ECG signal or the representation for ECG signal corrupted by noise [20] is given by

$$y(n) = e_{cg}(n) + p_{50}(n) \tag{3}$$

$$y(n) = e_{cg}(n) + \cos(\pi 0.05n) \tag{4}$$

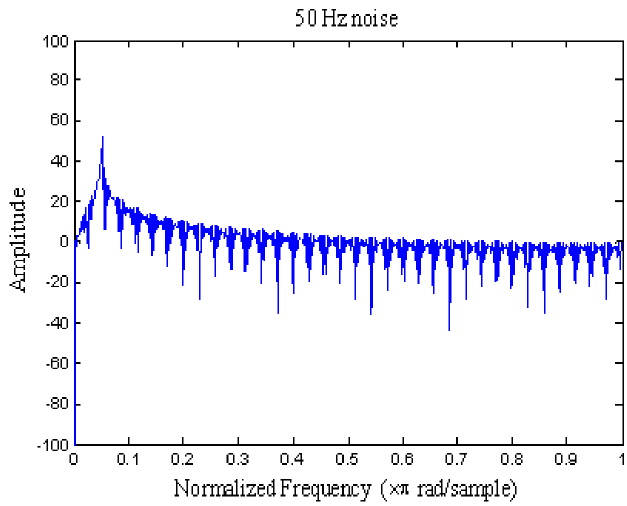

Figure 2. Noise signal for 50 Hz

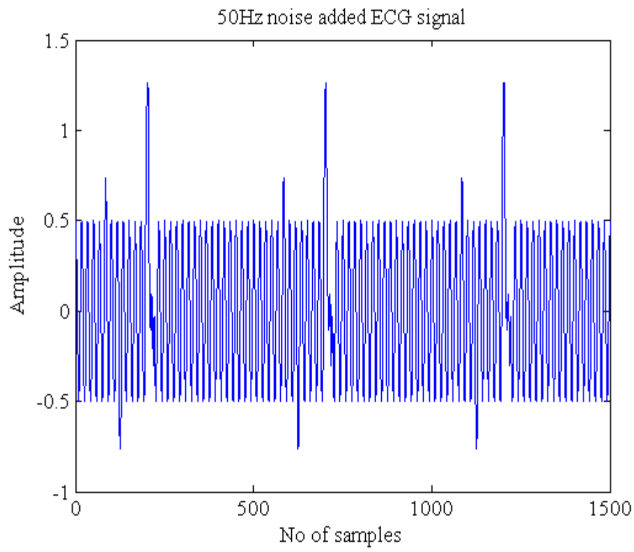

Figure 3. ECG signal with noise for frequency of 50 Hz

When a 50 Hz noise signal corrupts an ECG signal due to near by power line it can be represented through Figure 3. The 50 Hz power line noise corrupts the beats of the ECG signal [20] and makes it difficult for a medical physician to do diagnosis. This can be overcome by using a digital filter designed to remove that particular frequency of 50 Hz. The design of the digital filter [20] starts from the input output difference equation of a digital system which is given as

$$y(n) = x(n) - 1.79x(n-1) + x(n-2) + 1.79y(n-1) - 0.9y(n-2) \tag{5}$$

On rearranging the terms with x(n) as the input and y(n) as the output it is expressed as

$$y(n) - 1.79y(n-1) + 0.9y(n-2) = x(n) - 1.79x(n-1) + x(n-2) \quad (6)$$

The value of R^2 is found to be 0.9 and R= 0.9486 as per the input and output filter coefficients as per literature of Orfanidis [20]. Now in order to find the transfer function of the digital IIR filter it is necessary to take the z-transform of the above equation on both the sides and it follows as.

$$ZT[y(n) - 1.79y(n-1) + 0.9y(n-2)] = ZT[x(n) - 1.79x(n-1) + x(n-2)] \quad (7)$$

$$y(z) - 1.79y(z)z^{-1} + 0.9y(z)z^{-2} = x(z) - 1.79x(z)z^{-1} + x(z)z^{-2} \quad (8)$$

Proceeding further it is

$$y(z)[1 - 1.79z^{-1} + 0.9z^{-2}] = x(z)[1 - 1.79z^{-1} + z^{-2}] \quad (9)$$

Finally, the transfer function which is the ratio of the output to the input is given as

$$H(z) = \frac{y(z)}{x(z)} = \frac{1 - 1.79z^{-1} + z^{-2}}{1 - 1.79z^{-1} + 0.9z^{-2}} \quad (10)$$

The digital notch filter can be represented by the transfer function

$$H(z) = \frac{1 - 1.79z^{-1} + z^{-2}}{1 - 1.79z^{-1} + 0.9z^{-2}} \quad (11)$$

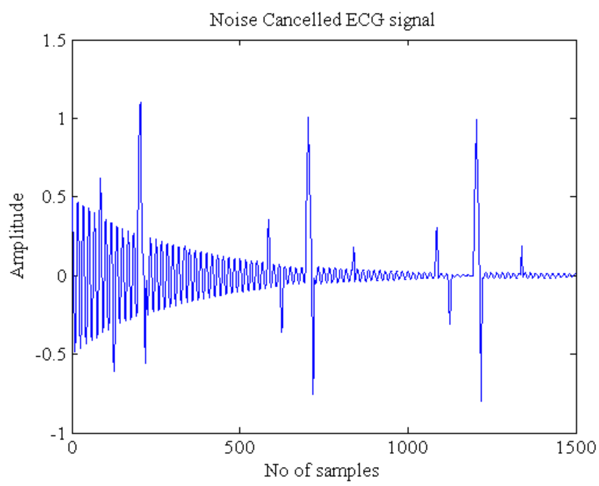

Figure 4. Noise cancelled ECG signal

The digital filter represented in (11) is a digital infinite impulse response (IIR) filter known as single frequency elimination filter or notch filter [20]. The digital filter has poles and zeros in the transfer function. If a noise added ECG signal is passed into a 50 Hz noise cancellation filter, the effect of noise is minimized so that ECG signal can be used for diagnosis as shown in Figure 4. Moreover, the digital filter can also be realized in terms of the basic building blocks of digital signal processing namely scaling element, summation element and delay element which can provide a possibility for hardware realization of the digital filter. Such hardware realization of digital filter can be obtained by direct form realization, canonical form realization, parallel form realization and lattice form realization [20] as shown in Figure 5.

Figure 5 shows the digital notch filter realization in direct form in accordance with the transfer function as per Eq. (11) in digital domain with z-transform. The filter has filter input as x(n) and output as y(n) with delay elements represented by z^{-1}, scaling elements for representing its scaling values and a summing element which can provide further insights for research domain perspective.

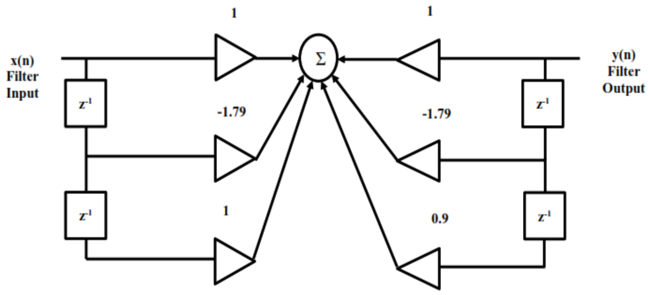

Figure 5. Digital notch filter realization direct form

3. COGNITIVE ECG SIGNAL RESULTS AND DISCUSSIONS

When cognitive user ECG signal is recovered through digital filter it needs to be sent to medical physician for proper diagnosis. The cognitive ECG signal is modulated and sent through cognitive radio technology which senses the available frequency through spectrum sensing technique and transmits the information by digital modulation scheme. Cognitive radio technology is an intelligent form of communication which transmits and receives data in next generation networks, can also be used in massive MIMO systems [21], machine learning methods [22, 23] and can also be fruitful for medical signal transmission and reception to cater medical signal processing and health care data [24].

The system model considers a cognitive radio system comprising of a primary user I acting as transmitter and a primary user II acting as receiver forming the licensed band is considered where spectrum sensing is done. The unlicensed band has the cognitive secondary user I and cognitive secondary user II. When a *N* x *1* data symbol vector $\mathbf{e}_{cg}$ is transmitted from the secondary user I to the primary user II the N x 1 received signal vector $\boldsymbol{y}_{cg}$ is

$$\boldsymbol{y}_{cg} = h_{cg}\boldsymbol{e}_{cg} + \boldsymbol{n}_{cg} \quad (12)$$

where, h_{cg} is a scalar channel coefficient in the cognitive radio system undergoing Rayleigh flat fading. Rayleigh flat fading channel has magnitude component which is statistically $h_{cg=}\sqrt{x_1^2 + x_2^2}$; where x_1 and x_2 are a Gaussian random variables and its phase component values take the mathematical representation $tan^{-1}\left(\frac{x_2}{x_1}\right)$. $\mathbf{n}_{cg}$ is $N \times 1$ a complex Gaussian noise vector with $N(\mu_x, \sigma^2)$ having mean μ_x and unit variance σ^2. The probability density function (PDF) of the Rayleigh flat fading channel is given by the Rayleigh distribution [25].

$$f(h_{cg}) = \begin{Bmatrix} \frac{h_{cg}}{\sigma^2} \; exp\left(\frac{h_{cg}^2}{2\sigma^2}\right); \; 0 \leq h_{cg} \leq \infty \\ 0 \qquad\qquad ; \; h_{cg} < 0 \end{Bmatrix} \tag{13}$$

On the other hand cognitive radio performance in Rician flat fading channel can be given by the following mathematical representation

$$\boldsymbol{y}_{cgric} = h_{ric}\boldsymbol{e_{cg}} + \boldsymbol{n}_{cg} \tag{14}$$

where, h_{ric} is Rician flat fading channel and it is also a line-of-sight (LOS) fading channel which is considered to be a complex variable where its magnitude is represented by K_{dB}. The Rician flat fading channel has Rician probability density function [25, 26] which is given as

$$f(h_{ric}) = \begin{Bmatrix} \frac{h_{ric}}{\sigma^2} e^{\frac{-(h_{ric}^2+A^2)}{2\sigma^2}} I_0\left(\frac{Ah_{ric}}{\sigma^2}\right); \; (A \geq 0; h_{ric} \geq 0) \\ 0 \qquad\qquad ; (h_{ric} < 0) \end{Bmatrix} \tag{15}$$

where, A is amplitude which determines the line-of-sight component for the Rician flat fading channel. If the value of $K_{dB}=0dB$ is equal to zero then it is considered to be Rayleigh flat fading channel. Table 1 shows the simulation testbed metrics.

Table 1. Simulation testbed metrics

Data Metrics	Simulation Parameters
Data signal	ECG Signal of 2 beats with 1500 samples
Filter	Notch Filter
Analog Frequency	50 Hz
Sampling Frequency	1kHz
Digital Frequency/Discrete Frequency	0.05 rad/sec
Modulation Scheme	Binary Phase Shift Keying (BPSK)
Fading channel	Rayleigh Fading Channel Rician Fading Channel
Monte Carlo Runs	1000
Assessment Metric	Probability of Error

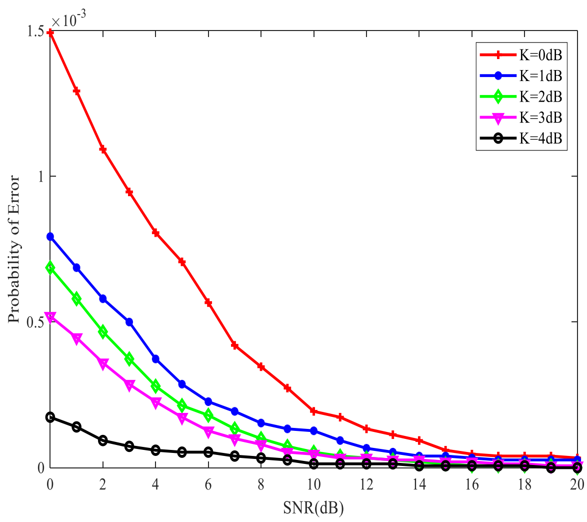

Figure 6. Probability of error performance of ECG signal under cognitive radio environment

Figure 6 shows cognitive ECG signal transmitted as data in the form of binary phase shift keying (BPSK) signal transmitted as +1 and -1 for phase shift of 0 degrees and 180 degrees. Each of the beats in Cognitive ECG signals are transmitted in this process and probability of error values are analyzed. Fading channel considered here is Rayleigh channel which implies *K=0dB* and when the fading channel experiences line-of-sight (LOS) channel such as Rician fading channel LOS components of *K=1dB,2dB,3dB* and *4dB* is simulated and it shows that the error rate reduces significantly from which the results are shown as in Table 2. When K=1 dB presence of line-of-sight component reduces probability of error in comparison to K=0dB. When the signal to noise ratio (SNR) of 6dB is reached, the probability of error reaches 5.6 x 10^{-4} for *K=0dB* and ultimately when *K=4dB* the probability of error reaches 0.5 x 10^{-4}. This infers that probability of error reduces significantly for the transmitted ECG signal making analysis significant. From the obtained signals the physician can give suggestions for human welfare making a distinct possibility for diagnosis and medical treatment when 5G and 6G systems are deployed with massive MIMO technology [21] for higher data rate requirement.

Table 2. Signal to noise ratio against probability of error

Signal to Noise Ratio	LOS Component	Probability of Error
	K=0dB	5.6 x 10^{-4}
6dB	*K=1dB*	2.3 x 10^{-4}
	K=2dB	1.8 x 10^{-4}
	K=3dB	1.4 x 10^{-4}
	K=4dB	0.5 x 10^{-4}

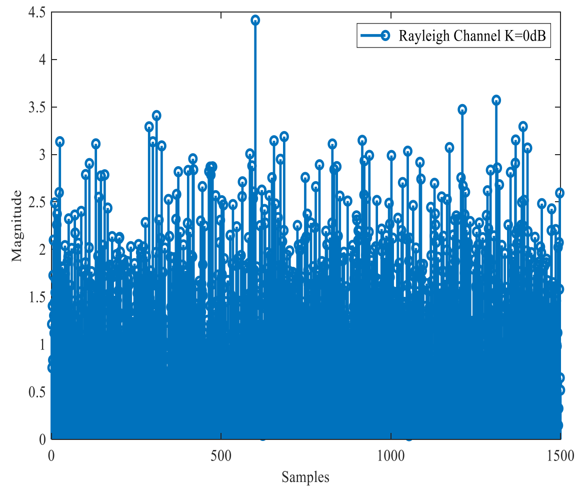

Figure 7. Rayleigh fading channel impulse response under cognitive radio environment

Figure 7 shows the channel impulse response obtained over entire 1500 samples taken into consideration during simulation for Rayleigh fading channel. Here the Rayleigh fading channel [25] has a flat response over the entire frequency of duration and they are also narrow band channels and it is also used to give the statistical nature of the channel. As the wireless channel is random it is usually measured by its statistical parameters such as mean and variance. Variance always specifies the amount of power level in a random signal, whereas mean is used to represent the first moment. The probability of error performance over Rayleigh fading channel is given as

$$P_{Ray} = \frac{1}{2}\left(1 - \sqrt{\frac{SNR}{(1+SNR)}}\right) \qquad (16)$$

Similarly Figure 8, shows the Rician fading channel impulse response observed in cognitive radio environment where the magnitude components are increased in comparison to Figure 7, due to the presence of a dominant line-of-sight component as it is given for *K=1dB*. However, when the dominant signal factor reduces it almost reaches to a Rayleigh fading channel and the probability of error reaches to the expression as that for Rayleigh fading cognitive radio environment.

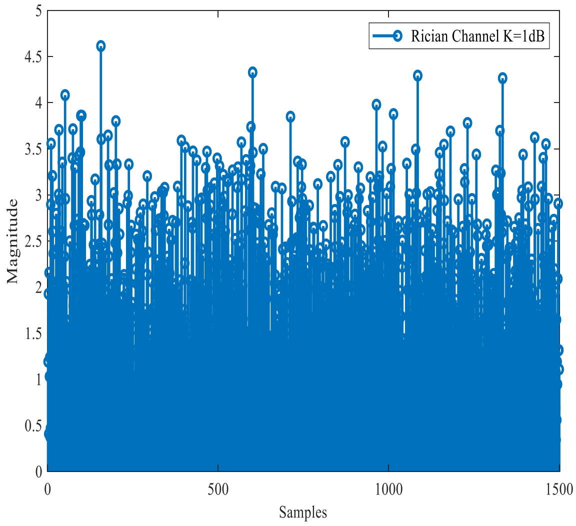

Figure 8. Rician fading channel impulse response under cognitive radio environment

4. CONCLUSIONS

This paper gives the conclusion that cognitive radio technology can be used for transmission and reception of ECG signals for proper diagnosis and recovery of human mankind. ECG signal corrupted by 50 Hz noise can be cancelled for noise by a properly selected digital filter which will give the correct readings of the ECG signal. Further, ECG signal can be transmitted to the medical physician mobile terminal through cognitive radio technology as ECG signal has only beats which can give an equivalent representation in the form of data. This sort of medical signal processing using cognitive radio will be beneficial for the human welfare and can lead to development of more applications relating to medical signal processing.

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