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A Review on Adaptive Filtering Techniques for Power Line Interference Removal from Biomedical Signals

Wasim Maroofi[#1], Tafhim Khan[#2], Sanjay R. Ganar[#3]
[#]*Electronics & Telecommunication Dept., Anjuman College of Engineering & Technology*

Abstract— The recorded signals tend to get contaminated with background noise and to extract the high-resolution ECG signals from them is a vital matter of exploration. The objective behind ECG signal enhancement is basically to isolate the valid signal components from the undesired artefacts, in order to yield an ECG that enables easy and exact interpretation. Numerous methodologies have been worked upon and reported in the paper to address ECG enhancement. Several kinds of noise exist in biomedical environment like Power Line Interference (PLI), baseline wander and noise due to muscles contraction and relaxation. Out of them, PLI is considered to be the key source of noise which seriously disturbs the characteristics of ECG signals. PLI removal is an essential task for investigating the ECG signal. PLI are of two types, namely stationary and non-stationary. Notch filters are employed to remove stationary power line interference and adaptive cancellers are used to handle non-stationary power line interference. The adaptive filter adjusts its filter coefficients in accordance with the adaptive algorithm. This paper discusses an effective adaptive algorithm used for eliminating power line interference from ECG signal. The filter algorithm is designed using MATLAB software and tested on ECG signal contaminated with several power line frequencies. The proposed method can also be employed to filter out the PLI even when corrupted ECG signal has low signal-to-noise ratio (SNR).
Keywords— ECG Signal, Power Line Interference, Adaptive Filter, Signal to Noise Ratio, Adaptive Algorithm, Percentage Mean Square Error(%MSE).

I. INTRODUCTION

Human body encompasses different kinds of biomedical signals, which upon examination, enables one to check the state of health of the concerned person. Out of such signals, Electrocardiogram (ECG) is one of them. ECG signal is the electrical representation of the activity of human heart over a period of time. Various cardiac diseases can be recognized with the help of ECG signal. During the recording process of an ECG signal, a number of noises may get added in it. The common types of noises are power line interference (PLI), electrode motion noise (EM), muscle artefacts, baseline wander etc. It is very important that we remove or minimize these interferences before further diagnosis for any medical application. A typical ECG tracing is a repeating cycle of three electrical entities: a P wave (atrial depolarization), a QRS complex (ventricular depolarization) and a T wave (ventricular repolarization). The QRS segment is very important and it is predominantly used for clinical observation. So if the noise changes the amplitude or time duration of the QRS segment then it may result in failure to exactly identify the true condition of patient. Hence, the primary concern is to pre-process the ECG signal, wherein our objective would be to isolate the valid signal component from the undesired noises so that the accurate interpretation of ECG could be carried out. In recent years, adaptive filtering technique has found its way as one of the most effective and popular methods for processing and analysing of the ECG and other biomedical signals. Adaptive filters allow the detection of time varying potentials and tracking of the dynamic variations of the signals. Moreover, they adjust their own behaviour according to the variations in the input signal. Therefore, they are able to sense shape variations in the ensemble leading to obtaining a better signal estimation. The research on the PLI removal is a hot topic of the biomedical field today. ECG signal mixed with the power line interference, affects the analysis of heart condition of patients, so it is inevitable to eliminate power-line interference effectively in ECG signal processing. The power-line interference can be assumed to be a sinusoidal wave. But practically, power-line interference signal is non-stationary. An effective adaptive algorithm for getting rid of power-line interference is proposed. In this work, the interference component from the input biomedical signal to estimate power-line interference is extracted. For a high quality analysis of the electrocardiogram (ECG), the amplitude of the power line interference should be less than 0.5% of the peak-to-peak QRS amplitude [1]. An ideal PLI suppression method should remove the

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PLI, while keeping the ECG signal intact.

The Fig. 1 is generalized block diagram of adaptive interference canceller. Adjustable filter is applied on the input signal x(n), to produce an output signal y(n). Adaptive filter adjusts the filter coefficients according to the adaptive algorithm in order to let the signal, e(n) be the smallest. Error signal e(n) is the difference of the desired signal d(n) and the filter output y(n).

The adaptive filter algorithm is used to adjust the coefficients of the adaptive filter such that the error signal, e(n) is minimized. Most commonly used adaptive algorithm is Least Mean Square (LMS) algorithm. It is used to adjust the weights of the adaptive filter in order to reduce the mean square error between the input signal and the reference signal. LMS algorithm brings with it some very important features that are good convergence in stationary environment, low computational complexity along with its stability and robustness for diversity of signal conditions.

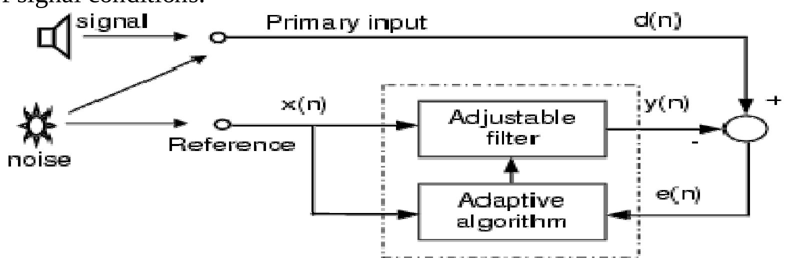

Fig. 1 Block diagram of the adaptive interference cancelling setup

During on-line examination of the patient and the doctors require to assess the ECG of the patient in real-time. Here, there is a great possibility that the ECG signal has been contaminated with noise. The predominant artefacts that are prevalent in the ECG include: Power Line Interference (PLI), Baseline Wander (BW) Muscle Artefacts (MA) and Motion artefacts (EM), which are caused by patient breathing, movement, bad electrodes and inappropriate electrode site preparation. The ST segments of ECG signals which are having low frequency are intensely affected by these contaminations, hence leading to incorrect diagnosis. In order to facilitate the doctors to get the best possible signal that can be obtained, an adaptive filter needs to be developed for noise removal in order to better obtain and deduce the ECG data.

II. RELATED WORK

The noise which greatly distorts the basic electrocardiogram (ECG) is power line interference (PLI). Several contributions have been made during past few years in this regard. Many researchers have worked on power line interference in ECG signal, summary of which is discussed below.

Widrow [6] proposed the elimination of PLI in the ECG by means of adaptive filtering, with the help of an external reference signal. Advantage of this work was to decrease stationary random interference periodic as well as random signals. But on the other hand, the disadvantage is that with each instant of accomplishment of PLI cancelling with little signal distortion, it always required external reference signal. Ahlstrom and Tompkins [7] worked on an adaptive 60-HZ filter for ECG signals using an internally generated reference signal. Also Ahlstrom and Tompkins' adaptive filter with an internally generated reference signal has less distortion, less complexity, and is more efficient in removal of low level 60-Hz noise. But this filter is almost analogous to a non-adaptive, second order, notch filter, suggesting that the performance of a non-adaptive notch filter and an adaptive notch filter with an internally generated reference is equivalent. If there arises a marginal difference in bandwidth then the transient response time of notch filter is also affected and this leads to the filter adapting more slowly to the changes in noise [7].

Implementation of nonlinear adaptive filter based on neural network[8], has an enhanced means to remove the baseline drift, pseudo-differential effects. However, the adaptive filter used in this work, is affected by effect of deviation of QRS wave, and has a vast restraint for the clinical application of ECG analysis. A. Ziarani and A. Konrad in [9] proposed an adaptive canceller setup based on first order phase adaptation system. The method presented in this paper consists of a simple and robust structure. The performance of the proposed nonlinear adaptive EMI filter and its application in the elimination of PLI present in ECG signals. The structure consists of lesser number of arithmetic operations having a high degree of resistance with respect to any ambient noise. The adaptive canceller proposed in [9] has been improved upon in [4] wherein the enhancement is achieved by means of replacing the first order phase adaptation system by a second order phase-locked loop (PLL) system. S. Marten [4] compared their improved adaptive power line interference canceller to the canceller which was proposed by Ziarani [9] which reduced the fundamental power line interference component in ECG recordings. The results in the design proposed by Ziarani depicted that the value of the adaptation constant vector for the adaptive canceller in [9] does not always lead to a successful acquisition phase. But, the design of canceller is such that the optimal adaptation constant vector is dependent on d(k) (interference signal) [4]. The adaptive canceller tracks the amplitude, phase and frequency of the fundamental component and harmonics of the PLI [4]. The gradient noise cause by the ECG signal and baseline wander is reduced by the error filter implemented in the adaptive canceller [4].

A novel method for removing PLI in ECG signals based on EMD and adaptive filter was proposed in [10], [12]. The performance of this particular technique was verified with actual ECG signals. EMD was developed as a non-parametric data-driven analysis tool for nonlinear and non-stationary signal processing. It has the ability to analyse signal with exceptional time resolution. The most widely used adaptive filtering algorithm is the least mean square (LMS) algorithm developed by Window and Hoff. Results indicate that with the help of this method the power line interference can be eliminated from the ECG signal without affecting its spectrum [10], [12].

A novel PLI detection and suppression algorithm was proposed to pre-process real time ECG signals based on recursive least square (RLS) adaptive notch filter instead of LMS adaptive filters[11],[12]. It first compares the energy at the harmonic frequency against the energy at neighbouring frequencies of the ECG power spectrum, and makes use of an optimal linear discriminant analysis (LDA) algorithm to determine whether PLI interference exists in the ECG signal. In case of detection of the presence of PLI, it then applies a recursive least square (RLS) algorithm to suppress the interference. Extensive simulation results show that the algorithm constantly shows better performance with respect to faster convergence rates, minimized ECG distortion and numerical stability [11], [12].

In noise cancellation application, LMS algorithm is usually used on adaptive filtering [13], [12]. Refining of the convergence properties of LMS algorithm along with reduction in the complexity showed slight enhancements in LMS adaptive filter algorithm, known as normalized variable step size LMS algorithm (NLMS). Though, a serious difficulty linked with both the LMS and NLMS algorithms is the selection of the step-size parameter that is a trade-off between the steady-state disturbance and the speed of adaptation [14],[12]. The paper in [14] presents an improved LMS algorithm of variable step length based on Kwong least mean-square algorithm which is used for an adaptive noise canceller. The sinusoidal signal and audio signal with Gaussian white noise were simulated in noise cancellation system on the MATLAB platform. It has fast convergence and better noise suppression ability than existing traditional algorithms.

H. N. Bharath and K. M. M. Prabhu proposed a method of error filtering and adaptive blocking. The performance of the windowed adaptive canceller (WAC) in suppressing PLI is compared with the IIR notch filter, the normal adaptive power line canceller (APC) and the improved adaptive canceller (IAC) proposed in [4]. The performance of the modified adaptive canceller is further improved by means of error filtering and adaptation blocking [5]. The WAC proposed in [5] provides the best performance for deviations of randomly varying frequency. When the frequency deviation is constant, the performance of windowed adaptive canceller (WAC) is poorer, when compared to the IAC. However, the proposed modified windowed adaptive canceller (WMAC) performs better than the IAC because its performance without adaptation blocking is rather poor in comparison to the WAC or the MWAC [5].

Wang Sanxiu and Jiang Shengtao have proposed an independent component analysis (ICA) technique to remove PLI from ECG signal in [15]. ICA is an innovative method of Blind Source Separation (BBS) [15]. Its aim is to separate mutually independent components from mixed signal, which is a linear combination of a set of mutually independent source signals. ICA algorithm not only preserves the original information but also filters the interference signal quite effectively. Additionally, the comprehension of ICA algorithm is simple and convenient with regards to calculation. ICA system is not perfect, a few practical issues remain to be resolved, and one such issue is the order of output component is uncertain, when the hybrid of source signal is nonlinear and the number of observed signals is less than number of source signal [15].

Another technique to remove PLI from ECG signal using multiple sub adaptive filter approach has been proposed by Ashraf Mohamed Ali Hassan in [16]. The multiple sub-adaptive filters are connected depending on the disintegration of error signals. In this method the simulation is repeated for as many times as the different number of sub-adaptive filters. After overall simulation, it is revealed that the proposed multiple sub-adaptive filters are able to achieve better SNR and MSE compared to the previously discussed approaches. As we go on increasing the number of sub-adaptive filters, better SNR and better MSE were attained. However, this occurs at the expense of cost and design complexity [16].

A method based on sliding discrete Fourier transform (SDFT) phase locked loop scheme (PLL)S was proposed by Mishra, Debasmit Das, R. Kumar, and P. Sumathi in [17]. The PLI canceller consists of the adaptive sampling frequency control in which the sampling frequency of SDFT filter is adjusted in an adaptive manner according to the center frequency variation of the interference. As the in-phase and quadrature components of SDFT filter are able to provide instantaneous sinusoidal and co-sinusoidal interference signals, the SDFT PLL is capable of tracking amplitude, phase, and frequency of the interference. The adaptive PLI canceller based on SDFT PLL offers the tracking capability of variant PLI, attenuation of 40 dB, less acquisition time of 0.2 sec for

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a variant PLI of ±5 Hz, removal of dominant odd harmonics, and baseline wander at the cost of sampling frequency. Nevertheless, this adaptive system needs four times more sampling frequency compared to other schemes [17].

An algorithm that is modified Log-LMS dividing the convergence process into two different stages, such as converging stage and extracting stage, exploits different quantization methods in each stage, has been proposed by Yuzhong Jiao, Rex Y. P. Cheung and Mark P. C. Mok in [18]. The algorithm assures fast convergence in the converging stage and low signal distortion in the extracting stage because this modified algorithm can utilize larger step size in the entire convergence process. Modified Log-LMS algorithm is able to achieve greater gains than traditional Log-LMS algorithm. Here two stages are involved, so the modified Log-LMS algorithm undoubtedly requires higher implementation complexity [18].

An adaptive filter with genetic algorithm was proposed by Bor-Shyh Lin, Bor-Shing Lin and Fok-Ching Chong [19]. The LMS algorithm is sensitive to the eigen value spread of the auto-correlation matrix of the reference signals, and the selection of its step-size. So, to overcome this inadequacy, they proposed the genetic adaptive filter. Genetic algorithm is insensitive to the altering step size of filter and provides better performance irrespective of the step size [19].

The LMS algorithm is the most used algorithm for minimizing the mean square error (MSE) of the system output in an iterative manner. In some practical applications, the LMS algorithm can be implemented merely with delayed coefficient adaptation [20], [12]. The use of delayed coefficient adaptation in the LMS algorithm has facilitated the design of modular systolic architectures [21], [12]. The convergence behaviour of this delayed least mean squares (DLMS) algorithm, when compared to that of the standard LMS algorithm, is degraded and worsens as the adaptation delay increases.

III.PROPOSED WORK

The proposed work is primarily focused on refining the SNR. Another significant factor to be improved upon is the correlation coefficient which establishes the relationship between filtered and non-filtered signal. The processes involved in this study may be listed as follows:

A. Comparative analysis of different available methods of adaptive power line interference removal from literature.
B. Choice of the diverse significant parameters to analyse the performance of the algorithm.
C. Explore a new method for removal of adaptive power line interference from biomedical signal.
D. Designing an algorithm for proposed method using software like MATLAB.
E. Analysis of the performance of implemented algorithm based on the significant parameters.
F. Comparison of performance of implemented algorithm with the available method in the literature.

Algorithm

```
Define the of k,φS, φI
vS=exp(1j*(i1)*2*pi*d*sin(øS));
vI=exp(1j*(i-1)*2*pi*d*sin(øI));
I=rand(N.k) %interference signal
for n = 1:k)
x = S(n)*vS + I(n)*vI/kalman equations;
%y = w*x.';
y=w'*x; %output signal
e = conj(S(n)) - y; %error signal
w=w+mu*conj(e)*x; %weights update
end
End
Arrayfactor=w* e-j(k) πsinφ
The equation for kalman filter is given by
p(n+1)+qv/σ(n+1)
```

Moreover, a pragmatic step size (μ) is used for algorithm updating and determining both how quickly the adaptive filter adapts to the filter solution.

The algorithm above uses the steepest decent method [4] and calculates the weight vector. Then the reconstructed signal's parameters such as SNR, percentage mean square error (%MSE) and error standard deviation (ESD) are evaluated to measure the performance of different adaptive filters [23]. In addition to the above algorithm, we propose to use the distributed arithmetic approach to minimize the complexity issue in the proposed structure. Distributed arithmetic (DA) is a computationally efficient approach which may be used to implement the Block Least Mean Square (BLMS) algorithm which may further reduce the computational complexity of adaptive filter. DA scheme employs bit-serial operations and look-up tables (LUTs) sharing and weight increment terms of BLMS algorithm to implement high throughput filters.

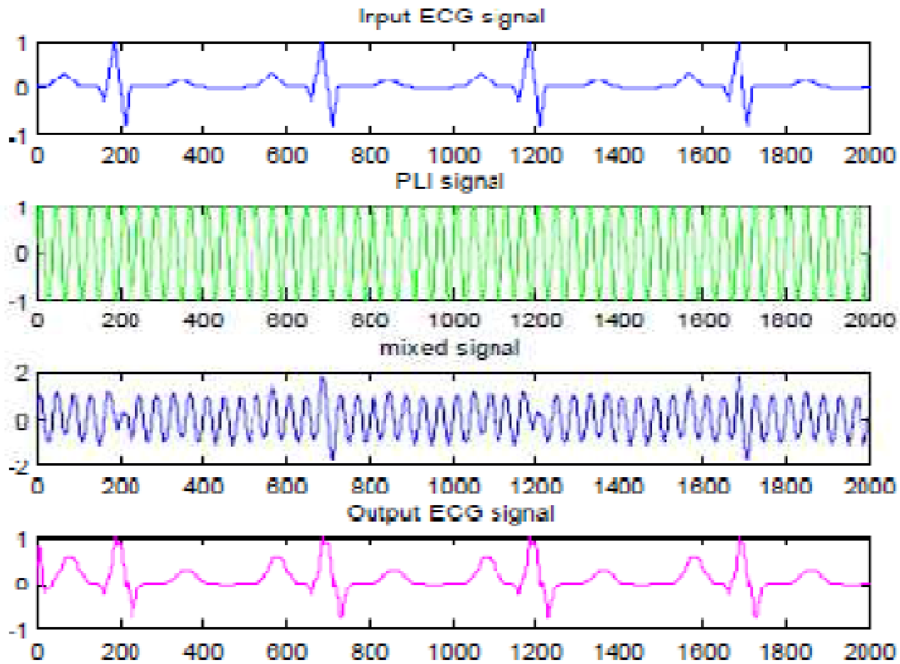

Fig. 2. Power Line Interference Removal Using Adaptive Filter

IV. CONCLUSION

In this review paper, the research work done by several authors has been put forward. From all the work done and discussed here, we can deduce that to remove Power line interference, the adaptive filter techniques are found to be the most appropriate. The adaptive filter can adjust its filter coefficients according to the adaptive algorithm in such a manner that the error signal, e(n) is minimized. In general, Least Mean Square (LMS) algorithm is implemented for adjusting the weights of filter coefficients of the adaptive filter in order to reduce the mean square error (%MSE) parameter between the input signal and reference signal.

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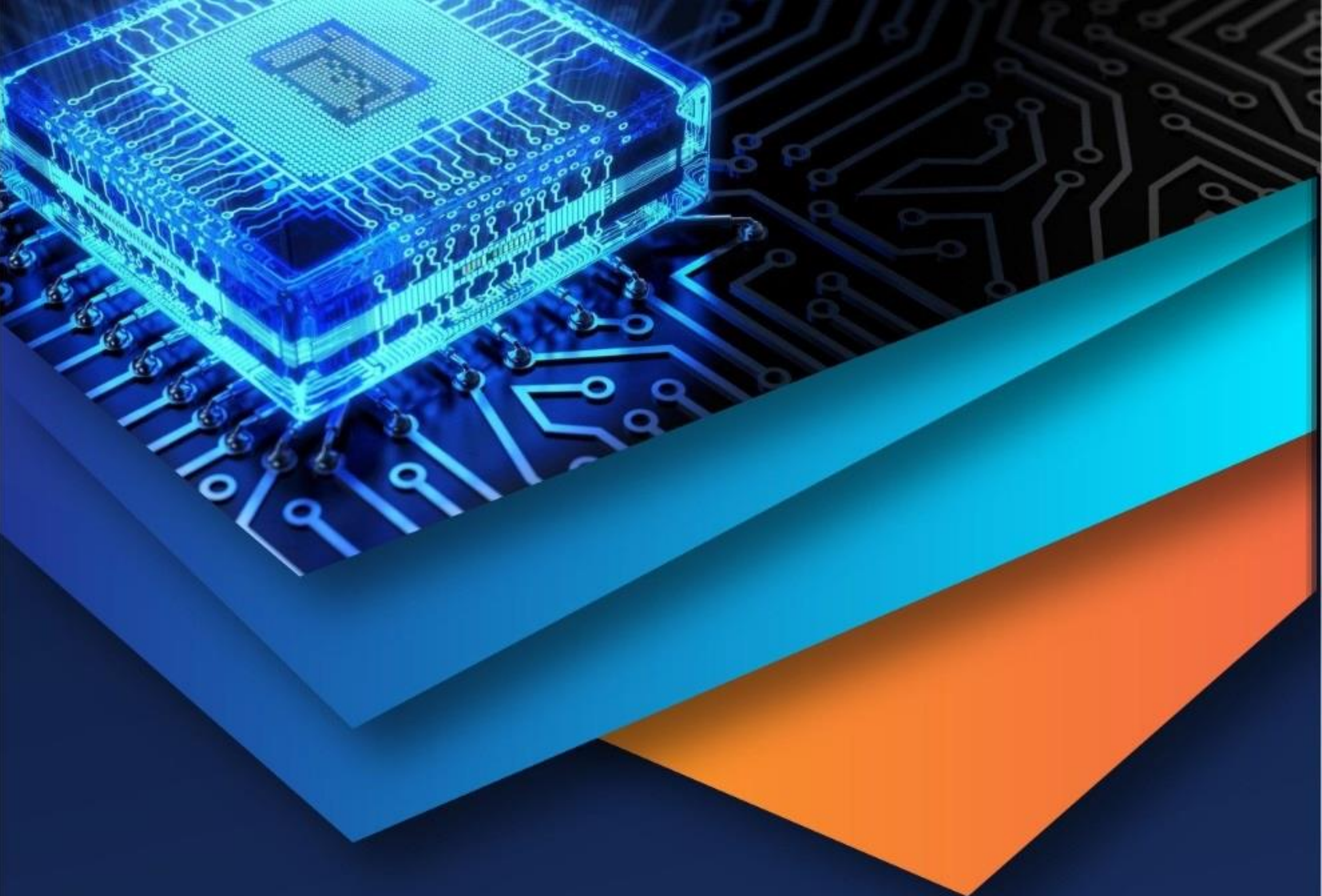

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