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Impact of Various implemented Digital Signal Processing Techniques on Quality Assessment of Retrieved Color Image in a Noisy Channel

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Abstract: *Noise is inevitable and ubiquitous in our natural environment. Noise reduction is a challenging task in various aspects of digital/ analog signal processing. In this paper, a comprehensive study has been made on the effectiveness of various digital signal detection techniques such as Ideal Inverse Channel Filtering, Minimum-mean-square-error (MMSE) and Cancellation of Correlation aided signal detection. From MATLAB based simulation study on 192×200 sized color image transmission in a noisy channel, it has been explored that the Cancellation of Correlation aided signal detection technique is very much effective and robust in retrieving data in highly noisy and hostile Channel*

Keywords: *Cancellation of Correlation aided signal detection, Ideal Inverse Channel Filtering,* Minimum-mean-square-error (MMSE) *based channel equalization/signal detection, noisy channel*

I. Introduction

Digital signal processing has always played a critical role in science and technology. In past few decades, the theory and applications of digital signal processing have evolved to play a central role in the development of modern telecommunication and information technology systems. Signal processing methods are central to efficient mobile communication, and to the development of intelligent man/machine interfaces in such areas as speech and visual pattern recognition for multimedia systems. In general, digital signal processing is concerned with two broad areas of information theory as:

- Efficient and reliable coding, transmission, reception, storage and representation of signals in communication systems such as mobile phones, radio and TV.
- The extraction of information from noisy and/or incomplete signals for pattern recognition, detection, forecasting, decision-making, signal enhancement, control, automation and search engines.

Signal processing methods provide a variety of tools for modeling, analysis, coding, synthesis and recognition of signals. Signal processing methods have evolved in algorithmic complexity aiming for the optimal utilization of the available information in order to achieve the best performance. In general, the computational requirement of signal processing methods increases, often exponentially, with the algorithmic complexity. However, the implementation costs of advanced signal processing methods have been offset and made affordable by the consistent trend in recent years of a continuing increase in performance, coupled with a simultaneous decrease in the cost of signal processing hardware. Depending on the method used, digital signal processing algorithms can be categorized into one or a combination of four broad categories. These are transform-based signal processing, model-based signal processing, Bayesian statistical signal processing and neural networks. In recent years, the development and commercial availability of increasingly powerful and affordable digital computers has been accompanied by the development of advanced digital signal processing algorithms for a wide variety of applications such as noise reduction, radar, sonar, video and audio signal processing, pattern recognition, geophysics explorations, data forecasting, and the processing of large databases for the identification, extraction and organization of unknown underlying structures and patterns**[1,2].**

II. Signal Detection/Channel Equalization schemes

In my present study, three signal detection/channel equalization schemes have been used. Brief overviews of these schemes are given below:

A. Inverse-Channel Filtering

In this study a resized RGB color image containing 192 x 200 x 3 array of color pixels with pixel values in the range [0,255] has been used as an input data . Its three color image components (Red, Green and Blue) are 96 x 96 pixel sized. As each pixel of the color image component is represented by 8 binary bits, the total number of binary for such a considered color image is 921600.The binary bits in 0/1 format are modulated using 64 QAM digital modulation scheme**[3].** The signal model in terms of transmitted signal vector $X \in C^{1024 \times 150}$, independent and identically distributed (i.i.d.) additive white Gaussian Noise $V \in C^{1024 \times 150}$, rapidly varying channel coefficient matrix $H \in C^{1024 \times 150}$ and received signal vector $Z \in C^{1024 \times 150}$ can be written as:

$$Z = HX + V \tag{1}$$

The whole transmitted data are rearranged into 150 blocks with each block containing 1024 digitally modulated symbols. The data are transmitted block wise in SISO channel.

It is considered that Equation (1) is time domain representation of different signals and it can be written in frequency domain as:

$$Z(f)=X(f)H(f)+V(f) \tag{2}$$

where , Z(f),X(f),H(f) and V(f) are the frequency spectra of the channel output, the channel input, the channel response and the additive noise respectively.

In inverse-channel filtering technique, an effort is taken to recover the original input from the channel output signal. In the frequency domain, the ideal inverse channel filter can be expressed as

$$H(f)\, H^{inv}(f) = 1 \tag{3}$$

In Equation(3), $H^{inv}(f)$ is the used to denote the inverse channel filter. In the frequency domain, the recovered channel input signal can be written

$$\tilde{X}(f) = H^{inv}(f) Z(f) \tag{4}$$

In signal detection/channel equalization technique, Inverse Fourier Transformation of Equation (4) is taken to retrieve the transmitted signal vector $\hat{X}$ as**[1]:**

$$\hat{X} = IFFT[H^{inv}(f) Z(f)] \tag{5}$$

B.MMSE based Signal Detection/Channel Equalization

In Least-square(LS) aided signal detection/channel equalization scheme, the estimated LS channel is :

$$\hat{H}_{LS} = (X^H X)^{-1} X^H Z = X^{-1} Z \tag{6}$$

In MMSE based Signal Detection/Channel Equalization scheme, the estimated channel is given by

$$\hat{H}_{MMSE} = W \hat{H}_{LS} \tag{7}$$

where, the weight matrix $W = R_{H\tilde{H}} R_{\tilde{H}\tilde{H}}^{+} (\tilde{H} = \hat{H}_{LS})$, $R_{H\tilde{H}}$ is the cross-correlation between the H and temporally estimated channel matrix $\tilde{H}$, $R_{\tilde{H}\tilde{H}}$ is the auto-correlation of the temporally estimated channel matrix $\tilde{H}$.The Moore-Penrose pseudo- inverse of matrix $R_{\tilde{H}\tilde{H}}$ is taken instead of general matrix inversion merely to avoid singularity/ badly scaling during MATLAB program execution The estimated transmitted signal is computed as:

$$\hat{X} = Z / \hat{H}_{MMSE} \tag{8}$$

In MATLAB notation using **for end** loop with specification of 150 iterations, the estimated MMSE channel (HMMSE) and estimated transmitted signal (XHT) can be written as**[4]:**

```
for m=1:150
HLS(:,m)= inv(diag(X(:,m))*(diag(X(:,m)))')*(diag(X(:,m)))'*(Z(:,m));
RHTHT(:,:,kkk)=HLS(:,kkk)*HLS(:,kkk)';
RHHT(:,:,kkk)=H(:,kkk)*HLS(:,kkk)';
```

```
HMMSE(:,kkk)=RHHT(:,:,kkk)*(pinv(RHTHT(:,:,kkk)))*HLS(:,kkk);
XHT(:,m)= Z(:,m)./HMMSE(:,m);
end
```

C. Cancellation of Correlation aided signal detection

The concept of spatial decor relation called also correlation cancelling plays an important role in signal processing. In Equation (1), the transmitted and received signal vectors X and Z are correlated i.e. $R_{zx}= E\{ZX^T\}\neq 0$ but the error or noise V is uncorrelated with X. The cross-correlation matrix between noise V and signal X can be written as:

$$R_{vx}== E\{ZX^T-HXX^T\}= R_{zx}-H R_{xx} \quad (9)$$

where, $R_{xx} = E\{XX^T\}$ is the autocorrelation matrix for transmitted signal. The estimated noise covariance matrix R_{vv} and channel matrix $\hat{H}$ can be written as:

$$R_{vv}== E\{VV^T\} =R_{zz} -R_{zx}R_{xx}^{-1}R_{xz} \quad (10)$$

$$\hat{H} =(R_{zz}- R_{vv})R_{xz}^{+} \quad (11)$$

where, R_{xz}^{+} is the Moore-Penrose pseudo- inverse matrix of $R_{xz,}$ and $R_{zz} =E\{ZZ^T\}$ is the autocorrelation matrix for received signal. The detected signal can be written as [2]:

$$\hat{X} = R_{xz}R_{zz}^{+}Z \quad (12)$$

III. Results and Discussion

In this section, a series of simulation results have been presented graphically to illustrate the significant impact of the digital signal processing techniques on reliable extraction of color image from a noisy and distortion producing channel. The simulation study has been made using MATLAB 2014a based on the parameters given in Table 1. The performance index is estimated in terms of no. of correctly retrieved bits out of 921600 binary bits forming the color image at two signal to noise ratio(SNR). In zero dB, the signal power is identical with noise power and in -10dB, the noise power is relatively greater than signal power by 10 dB.

Table 1 Summary of the Simulated Model Parameters

Data type	Color image: 192 × 200× 3 pixels with 921600 Binary bits
Data Modulation	64 QAM
Signal detection/Channel Equalization	Cancellation of Correlation aided signal detection, Ideal Inverse Channel Filtering, Minimum-mean-square-error(MMSE) based channel equalization /signal detection
Channel	AWGN
Signal to noise ratio, SNR	-10 dB, -5dB , 0 dB and 10 dB

In Figure 1, the transmitted color image and its different components are presented. In Figure 2, it is clearly noticeable that the quality of the retrieved images deteriorate with implementation of ideal inverse-channel filter based signal detection technique under a scenario of identical signal and noise power. The retrieved images are recognizable and the estimated performance index is 97.92 % with a bit error rate of 0.0208 .In Figure 3, the quality of the images deteriorate . The estimated performance index is found to have a value of 91.71 % with a bit error rate of 0.0829. In Figure 4, noise contamination is very much prominent. The estimated performance index is 79.44 % with a bit error rate of 0.2056. In Figure 5, it is observable that that the quality of the retrieved images are highly deteriorated with implementation of MMSE based signal detection technique under a scenario of identical signal and noise power. The estimated performance index is 61.70% with a bit error rate of 0.3830. In Figure 6, it is quite obvious that the quality of the retrieved images are little bit improved to a higher SNR value of 10 dB. The estimated performance index is 74.82% with a bit error rate of 0.2518. The graphical illustrations presented in Figure 7 ratifies that the quality of the retrieved images are highly noise free with implementation of Cancellation of Correlation aided signal detection technique under both zero dB and -10dB. The estimated performance index is 100% with no bit error rate found. In Figure 8, a three dimensional perspective plot of performance indicator is shown which implies that the system shows most satisfactory performance with Cancellation of Correlation aided signal detection and worst performance with MMSE based technique.

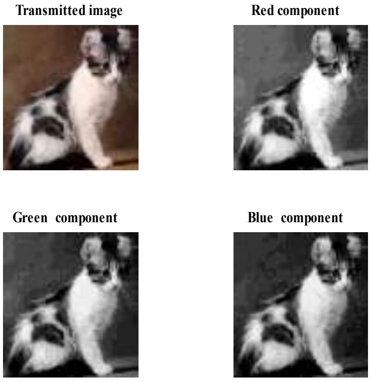

Figure 1: Transmitted color image and its three components

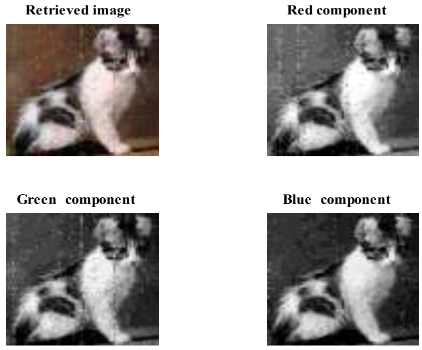

Figure 2: Retrieved color image and its three components under implementation of ideal inverse-channel filter based channel Equalization technique at 0 dB SNR and 64QAM digital modulation with SNR value of zero dB

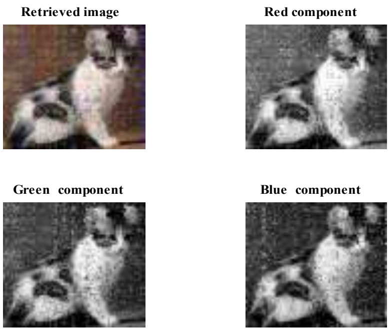

Figure 3: Retrieved color image and its three components under implementation of ideal inverse-channel filter based channel Equalization technique at -5 dB SNR

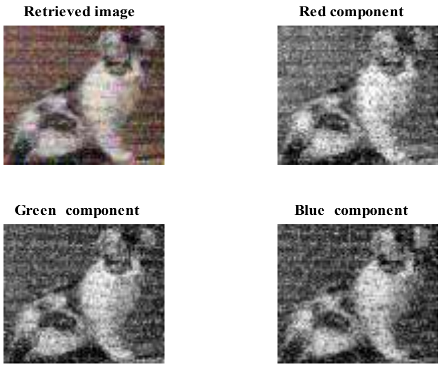

Figure 4: Retrieved color image and its three components under implementation of ideal inverse-channel filter based channel Equalization technique at -10 dB SNR

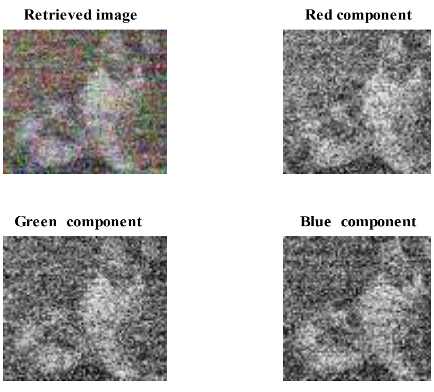

Figure 5: Retrieved color image and its three components under implementation of MMSE based channel Equalization technique and 64QAM digital modulation with SNR value of zero dB

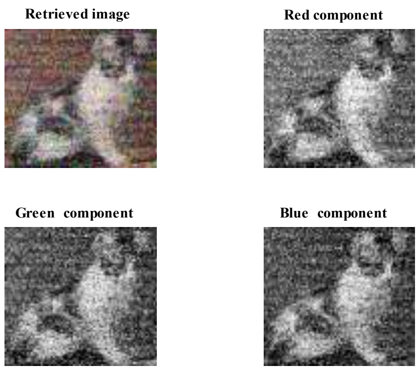

Figure 6: Retrieved color image and its three components under implementation of MMSE based channel Equalization technique and 64QAM digital modulation with SNR value of 10 dB

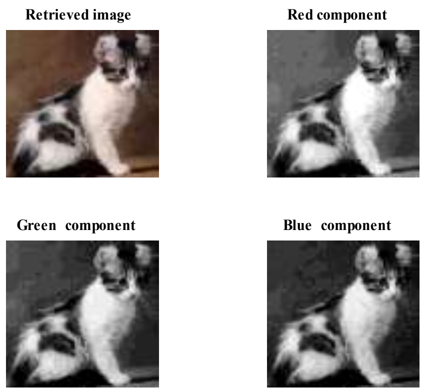

Figure 7: Retrieved color image and its three components under implementation of Cancellation of Correlation aided signal detection and 64QAM digital modulation with SNR value of -10 dB/0 dB

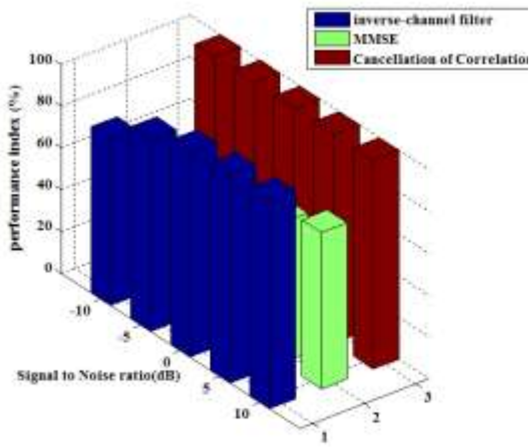

Figure 8: Three-dimensional perspective bar plot showing performance index for various implementation of various digital signal processing techniques

IV. Conclusions

In this paper, various digital signal processing techniques have been implemented to observe critically the quality of the color image transmitted in a noisy channel. Simulation results indicate the Cancellation of Correlation aided signal detection technique is very much effective and robust in retrieving color image with well recognizable form. As compared to other MMSE and Ideal Inverse Channel Filtering aided digital signal processing techniques, it can be concluded that the Cancellation of Correlation aided signal detection is a reliable digital signal processing technique capable of significant reduction of noise and distortion inferred from the channel

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V. References

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