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Enhanced Grayscale Image Transmission Over HF Channel

Ahmed S. Mashaly and Tamer Mekkawy
Avionics Department, Military Technical College, Cairo, Egypt
E-mail: mashaly@mtc.edu.eg, mekkawy@mtc.edu.eg

Abstract. Image transmission over HF communication is suitable for long-distance coverage beyond the line of sight and across intercontinental. Unfortunately, the channel condition is degraded with low Signal to Noise Ratio (SNR) and multi-path spreading. In this paper, we aim to transmit images over HF channel and introduce some techniques to improve the received noisy images. First, a Least square estimation technique is applied to estimate the channel state information, then we propose an enhanced filter to reduce image noise effect and improve the received image appearance. This proposed enhanced filter is based on our enhanced version of the Median Filter (MF) and the Mathematical Morphology (MM). Simulation results assess the performance of the proposed filter compared with the performance of some popular filters, we conclude that the proposed enhanced filter can be used for any further detection and recognition operations, and it introduces promising results which can be used for real-time implementation with different computer vision applications.

1. Introduction

HF communication has an important value for military and civilian applications. Actually, the radio waves of HF communication travel beyond the line of sight and can be transmitted to intercontinental distances, where radio waves is transmitted with an angle to the sky to be refracted back to the Earth from the ionosphere layer (skywave propagation) [1]. Unfortunately, some important issues should be considered when using HF communication, such as the sudden increases in the critical frequency of the ionospheric region during the sunrise, the large amount of noise associated with the ionospheric region based on the electron density (unrelated to specific solar or magnetic event), and the interference due to the congested spectrum. These affect the quality and reliability of the HF communication. Recent researches have significantly overcome some of the problems associated with HF communications [2]. New HF systems are now able to select the most appropriate channel to establish and maintain communications, keep the quality of voice and transmit data and facsimile, while their operations have been considerably simplified [3].

Designing efficient image communication system over HF channel is a desirable capability especially for surveillance. But, the processing capability and channel conditions are important challenges. Channel conditions can be estimated by different techniques such as Least Square (LS) and Min-Mean Square Error (MMSE) thanks to pilot symbol assisted [4]. After channel estimation, the images received over HF channel still have noise which affect the received image appearance. Thus, image processing techniques may adopted to reduce the image's noise effect and to improve the received image appearance. In Linear filters, such as mean filter, the output changes linearly with a change in the input and it is used for smoothing purpose. However, nonlinear filters are those for which the linearity relationship breaks down such as Median Filter (MF) [5], which is used to remove the outliers and shot noise that is independent of magnitude, in another words the non-linear technique enhance the corrupted image. Mathematical morphology (MM) [6] technique is used for analyzing the geometrical structures, based on lattice theory and random functions. Mainly, MM was developed for binary images, then it extended to grayscale images. The basic MM operators are erosion, dilation, opening and closing [7–9].

In this paper, we design a grayscale transmission images over HF channel. First, an LS estimation technique is applied for channel estimation, then we propose an enhanced filter to reduce image noise effect and improve the received image appearance. This proposed enhanced filter is based on a novel enhanced version of MF and MM. The simulation results assess the performance of the proposed filter compared with the performance of some popular filters. The rest of the paper is arranged as follows: in section 2, we introduce the system model used in image transmission. The channel estimation technique is presented in section 3. Then, the proposed enhanced filter is discussed in section 4, andthe experimental results and performance assessment are simulated in section sec:reslts.

2. System Model

OFDM is considered as an efficient modulation technique which transmits simultaneously a large number of sub-carriers, then each sub-carrier uses a slowly modulated narrow band signal. Therefore, it can adapt easily to several channel conditions with simple equalization, achieves high throughput, and also it is robust against inter-symbol interference. In this section, we show the OFDM system model used for images transmission over HF channel, where a set of encoded Quadrature Phase Shift Key (QPSK) symbols in frequency domain are collected to form an OFDM symbol. Then, an Inverse Fast Fourier Transform (IFFT) with length N is adopted to convert the OFDM symbol to time domain samples as follows:

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=1}^{N} X_k e^{j\frac{2\pi}{N}kn}. \tag{1}$$

Then, the received OFDM symbol are given by $y_n = \sum_{l=1}^{L} h_t x_{n-l} + N$, where L is the total number of resolvable propagation paths, h_t denotes the channel impulse response during the symbol interval, and N is the Additive White Gaussian Noise (AWGN) with zero mean and variance σ^2, then Fast Fourier Transform (FFT) is performed to get the cross frequency domain symbols. Although, HF communication is suitable for long distance communication because the ionosphere layer reflects the transmitted signals back to Earth. Unintentionally, the propagation through ionospheric layer affected by multipath and fading. Thus, the multipath components existed at the receiver are spread in time with several milliseconds. Watterson [10] channel model is utilized to evaluate the performance of HF communication systems, by modeling each resolvable propagation path as a tap in tapped delay line as represented in Fig. 1. Such that, each path is delayed and multiplied with tap gain (variation in signal phase and amplitude), then all the paths are summed with AWGN. As a result, the frequency response of Watterson channel is defined as:

$$H = \sum_{i=1}^{L} e^{-i2\pi\tau_i f} G_i. \tag{2}$$

where τ_i is the path delay, and G_i is the tap-gain function. Next section illustrates the channel estimation method which is used to enhance the quality of images transmission over HF channel.

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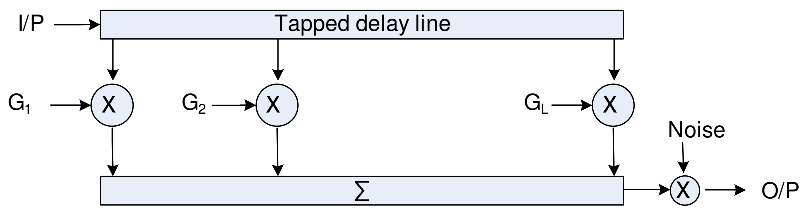


Figure 1: Watterson Channel Model

3. Channel Estimation

Practically, channel estimation in wireless communication can be performed by transmitting known symbols to detect the channel effect over that known symbols. Actually, it is impossible to know the complete transmission sequence, thus only a series of known position pilots are transmitted, x_p, and the missing positions are computed by interpolation. Let Z is the number of positions reserved for channel estimation purpose, then the received pilots are given as:

$$Y_{\mathrm{p}} = \sum_{p=1}^{Z} h_{\mathrm{p}} x_{\mathrm{p}} + N \tag{3}$$

By ignoring AWGN, a scalar form of the noisy channel for the pilots can be formed as $\hat{h_{\mathrm{p}}} = \frac{y_{\mathrm{p}}}{x_{\mathrm{p}}} = h_{\mathrm{p}} + \hat{N}$, where y_{p} is the received pilot $\hat{N} = N/x_{\mathrm{p}}$. Then, the least square cost function $\left\|y_{\mathrm{p}} - x_{\mathrm{p}}\hat{h}\right\|^2$ can be minimized [4] and by setting its derivative to zero as:

$$\frac{\partial \left\|y_{\mathrm{p}} - x_{\mathrm{p}}\hat{h}\right\|^2}{\partial \hat{h}} = -2\left({x_{\mathrm{p}}}^{\mathrm{H}} y_{\mathrm{p}}\right) + 2\left({x_{\mathrm{p}}}^{\mathrm{H}} x_{\mathrm{p}} \hat{H}\right) = 0 \tag{4}$$

Then, the channel coefficient for the pilots' positions can be estimated as

$$\hat{h_{\mathrm{LS}}} = \left({x_{\mathrm{p}}}^{\mathrm{H}} x_{\mathrm{p}}\right)^{-1} {x_{\mathrm{p}}}^{\mathrm{H}} y_{\mathrm{p}} = {x_{\mathrm{p}}}^{-1} y_{\mathrm{p}} \tag{5}$$

Based on (5), the channel coefficient at pilot position is estimated with LS technique, and the missing channel coefficients for the channel are calculated by performing some interpolation. Therefore, the equalized received symbol can be simply obtained. Fig. 2 shows the improvement of image transmission over HF channel when 64 sub-carriers OFDM are used with 12kHz channel bandwidth and QPSK symbol mapping, here we use 10 pilots for channel estimation with spacing 7 sub-carriers (the first and the last sub-carriers are pilots), and we choose a Cyclic Prefix (CP) length 16 (quarter overall sub-carriers) to resist to multipath interference. In Fig. 2, the image with LS technique is clearer than the image without estimation as expected when Signal to Noise Ratio (SNR)=20 dB. Moreover, the constellations for the image are shown and the Bit Error Rate (BER) are found 10^{-3} and 10^{-1} for the image with LS technique and without estimation, respectively.

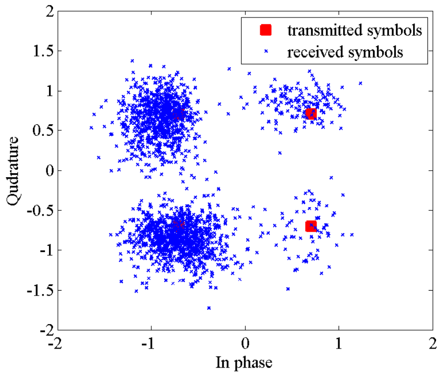
It is clear from Fig. 2 based on visual inspection index, that the LS technique improve the image transmission. However, the image quality still needs some enhancement, which motivate us to introduce an enhanced filter, which degrade the noise effect and enhance the image appearance .

4. The proposed Enhanced filter

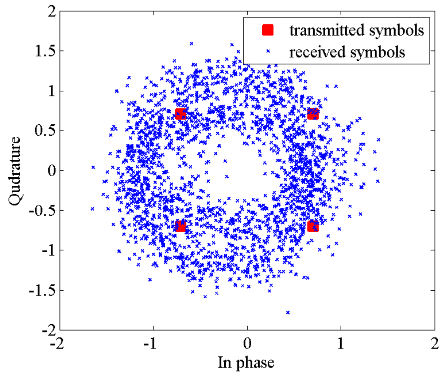
In this section, we introduce the main concept of our proposed enhanced filter. The proposed enhanced filter is used to compensate the resultant image distortion due to the transmission process over HF channel with LS estimation technique as described section 3. The main objective

(a) Received image with LS technique

(b) Received image without channel estimation



(c) QPSK constellation with LS technique



(d) QPSK constellation without channel estimation

Figure 2: Image Transmission over HF channel at 20dB.

of the proposed enhanced filter is to reduce the effect of image noise (*i.e.*, improve the overall SNR for the received image). In addition, we aim to enhance the final image appearance (*i.e.*, keep and enhance the information of image feature point). Therefore, we introduce an accurate, fast, and simple enhancement method to improve the quality of the transferred image via HF channel. The core of the proposed method is the well-known MF and the popular MM image tools. As a result, we classify the proposed enhanced filter as a non-linear filter. Using such non-linear filters has great advantages over the linear filters (*e.g,* Mean filter). Actually, non-linear filter may has great capability to reduce the noise while keeping the sharpening of edge appearance for the images under-process [11].

Simply, the proposed enhanced filter consists of two main steps; which are a modified version of well-known MF followed by a sequence of MM operations. For traditional MF, there are some limitations of using such filter for enhancing the quality of image transmission via HF channel, because the resultant image noise has a random distribution, which limits the overall performance of the traditional MF. Therefore, we propose a modified version of MF to overcome the random behavior for this type of noisy image. The modified version of MF relies on processing some grayscale intensity levels instead of single grayscale intensity value. Where, the final filtered grayscale level for each image pixel depends on the two adjacent grayscale levels (upper and lower ones) of the sorted version of the filter kernel as

$$i_{\text{filtered}} = \frac{i_{k-1} + i_k + i_{k+1}}{3} \tag{6}$$

Then, the modified MF is followed by a sequence of MM operations to remove the residual effect of the image noise. In this step, we use the conventional MM operations (erosion and dilation) with a Structure Element (SE) size of (3×3). For grayscale morphological erosion operation, it is defined as : the minimum value of the image in the region coincident with b when the origin of b is at (x, y). In equation form, the erosion at (x,y) of an image f by structuring element b is given by [7]

$$[\mathfrak{f} \ominus b]\,(x,y) = \min_{(s,t)\in b} \{\mathfrak{f}(x+s, y+t)\} \tag{7}$$

On the other hand, the grayscale morphological dilation operation is the dilation of $\mathfrak{f}$ by a flat structuring element b at any location (x, y), which is defined as the maximum value of the image in the window outline by $\hat{b}$ if (x, y) is the origin of the $\hat{b}$ [8]

$$[\mathfrak{f} \oplus b]\,(x,y) = \max_{(s,t)\in b} \{\mathfrak{f}(x-s, y-t)\} \tag{8}$$

Conceptually, the morphological erosion operation results a darker image. While, the morphological dilation operation results an image which seems to be brighter than the original one. Such operations with that sequence cancel the effect of each operation and keep the grayscale level unchanged. Theoretically, using an erosion operation followed by a dilation operation is a well-defined operation that is called a morphological grayscale opening operation as [?]

$$\mathfrak{f} \circ b = (\mathfrak{f} \ominus b) \oplus b \tag{9}$$

Finally, Fig. 3 represents the proposed enhanced filter block diagram, which based on a modified version of MF and MM opening operation. In the following section, we evaluate the performance of the proposed enhanced filter experimentally.

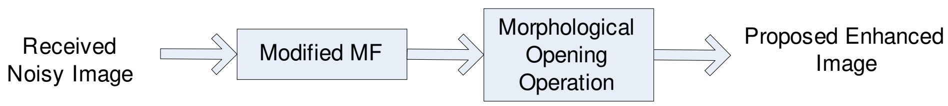


Figure 3: Block diagram of the proposed enhanced filter.

5. Performance Assessment

5.1. Quantitative Evaluation Indexes

Before starting the experimental results and performance assessment, we need to define our evaluation indexes which are used to measure the performance of the proposed enhanced filter compared with the performance of other well-known filters. There are four main quantitative parameters [6]:

- SNR Index: it gives a good indication about the signal level w.r.t. image noise level. Generally, High SNR value means that good enhancement process, SNR_{index} is defined mathematically as:

$$SNR_{\text{index}} = 10 \log \frac{\sigma_{\text{s}}^2}{\sigma_{\text{b}}^2} \tag{10}$$

where σ_{s}^2 denotes the variance of the signal, and σ_{b}^2 is the background variance.

- Normalized Mean (NM) Index: it examines the filter ability to preserve the mean information of the homogeneous regions in the filtered image compared with the original image as:

$$NM = \frac{\mu_{\text{filter}}}{\mu_{\text{original}}} \tag{11}$$

where μ_{filter} and μ_{original} are the mean of the background segment of the filtered and the original image, respectively. Such that, the closer NM to 1 is the better filter ability to preserve image information.

- Standard Deviation to Mean (STM) Index: it determines the filter ability to reduce image noise for the homogeneous regions, and it is defined as:

$$STM = \frac{\sigma_{\text{c}}}{\mu_{\text{filter}}} \tag{12}$$

where σ_{c} is the standard deviation of the filtered homogeneous region, and the small STM value indicates better noise reduction ability.

- Edge Index (EI); it computes the filter ability to preserve the detailed edge information, which equals to:

$$EI = \frac{\sum P_{\text{f}}(i,j) - P_{\text{f}}(i-1,j+1)}{\sum P_0(i,j) - P_0(i-1,j+1)} \tag{13}$$

where Where $P_{\text{f}}(i,j)$ and $P_0(i,j)$ are the filtered and the original image pixel values for the edges of the selected background segment, respectively. Such that, if $EI = 1$, the filtered edge information is similar to the original image, but the edge blurring occurs when $EI < 1$, and $EI > 1$ indicates edge enhancement.

Besides that, two additional evaluation indexes are used to evaluate the overall performance of the proposed filter that are visual inspection index, and the complexity index. For visual inspection index, it is an important evaluation index, and it is the first evaluation index that should be taken into consideration for evaluating the proposed enhanced filter. Where the visual inspection decides how much the enhanced image is applicable, useful and its appearance is close to its actual shape and boundary in the real world. On the other hand, the last evaluation index is the complexity index. This evaluation index is a critical parameter, we choose the average processing time per frame index, which indicates the complexity level of the evaluated filter. Since the processing time of each filter indicates its capability for real-time applications.

5.2. Experimental Results

Here, we evaluate the performance of the proposed enhanced filter by comparing it with some well-known filters like, mean, median, morphological opening filters. The task of this performance evaluation is to determine the ability of the proposed filter to enhance and restore the appearance of the received image via HF channel after LS technique. For this task, our experiments are performed on several standard images that are usually used for such kind of performance evaluation as shown in Fig. 4. All simulations and implementations are performed over NI-LabVIEW 2015 and NI-Vision Development System 2015, which are executed on Lenovo notebook Z50-70 with Intel processor I7 2.6 GHz (4510u) and 8 GB RAM.

For performance evaluation, we discuss the six evaluation parameters presented in subsection 5.1. Firstly, we represent the received noisy image after LS technique in Fig. 5, where the effect of HF channel is obviously still exist. For visual inspection evaluation index, we compare the response of mean, median, morphological opening and the proposed enhanced filter as shown in Figs. 6 and 7. It is clear that our proposed enhanced filter has the ability to enhance and

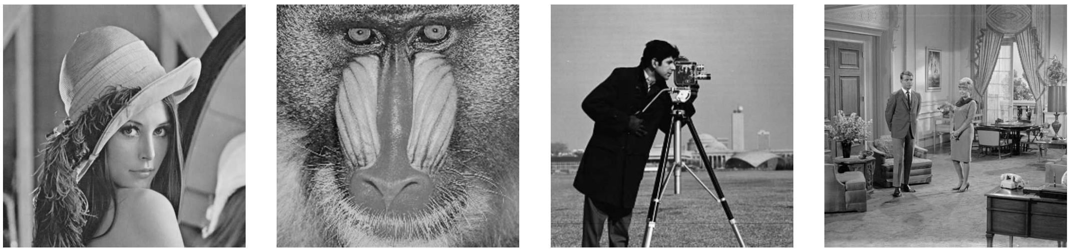


Figure 4: A sample of used dataset for performance evaluation.

Figure 5: A sample of received noisy images after LS technique.

(a) (b) (c) (d)

Figure 6: Response of different filters on data set 1 (a) Mean; (b) Media; (c) Morphological opening; (d) Proposed enhanced filter.

(a) (b) (c) (d)

Figure 7: Response of different filters on data set 3 (a) Mean; (b) Media; (c) Morphological opening; (d) Proposed enhanced filter.

remove the effect of noise that appear in the received images over HF channel after LS estimation technique.

Then, we compare the other evaluation parameters for the proposed enhanced filter in Table 1. We calculate the results in Table 1 by averaging the parameters of 40 grayscale images. Based

Table 1: Experimental Results for Proposed Enhanced Filter.

Filter	SNR_{index}	NM	STM	EI	complexity
Mean	5.82	0.95	0.17	0.93	0.58
Median	6.07	0.94	0.13	0.95	0.52
MorphologicalOpening	4.22	0.82	0.21	0.84	0.3
ProposedEnhanced	8.15	0.91	0.1	0.91	0.42

on the SNR_{index} for the filters under consideration, it is clear that the proposed enhanced filter provides the highest SNR values, which means that the proposed filter has promising results compared with the other filters. According to SNR result, the proposed filter response facilities any further detection or recognition steps.

By illustrating the normalized NM index, we conclude that the proposed enhanced filter has a good ability to preserve the mean information of the homogeneous regions in the filtered image compared with the original image (i.e. the information rejection factor of the proposed filter is quite low). By discussing STM index, we prove that the proposed enhanced filter presents the lowest value. Thus, the proposed enhanced filter has a great capability to reject and enhance the processed noisy images which appears after LS technique. According to the definition of EI, we conclude that all filters response introduce a burled images due to its processing behavior, because all EI values are less than one. For complexity evaluation index, the main evaluation factor is the average processing time per frame as we mentioned before. We observe that our proposed enhanced filter has a moderate processing time compared to the different filters type; it has less processing time than median and mean filters, however it requires more processing time than MM Opening filter. As a result, the proposed filter has the opportunity for real-time implementation for different computer vision applications. Finally, by comparing the results of the proposed filter with other filters, we conclude that the proposed enhance filter has superior results.

6. Conclusions

In this paper, we aim to transmit images over HF channel because HF communication is used for long-distance coverage beyond line of sight and across intercontinental. Unfortunately, the received image affected with different channel conditions which results noisy image. Thus, we introduce some techniques to improve the received noisy images. First, a Least square estimation technique is applied for channel estimation, then we propose an enhanced filter to reduce image noise effect and improve the received image appearance. This proposed enhanced filter is based on a novel enhanced version of median filter and mathematical morphology. Simulation results assess the performance of the proposed filter compared with the performance of some popular filters, we conclude that the proposed enhanced filter can be used for any further detection and recognition operations, and it introduces promising results which can be used for real-time implementation with different computer vision applications.

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