Recovery of Quality in Print–Scan Images

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Abstract **--In this paper, we propose a novel method for improving digital image recovery from print – scan channel. A printed photograph is not sufficient to recover the original digital image because of distortions introduced in scanning process. The proposed approach recovers the print – scan images with improved quality. We solve this approximation problem by combining both the photograph and the digital auxiliary information in the same printed material. Digital auxiliary information is composed of small amount of digital data, which enables accurate image recovery. The proposed technique consists of two main processes namely encoding and decoding. Encoding process generates auxiliary information and it is kept together with the print. Decoding process uses the Auxiliary information along with the scan of the printed photograph to eliminate the distortions introduced during scanning process. Our experimental results confirm that the proposed approach recovers the digital image with high quality by using reduced amount of auxiliary information.**

***Keywords* - Auxiliary Information, Encoding, Decoding, Distortions**

I. Introduction

A printed digital photograph is difficult to reuse because the quality of the printed image may not be good and the corresponding digital information that generated the print for recovering the original image is not available. We solve the approximation problem to recover the original digital image by combining the scan of the print together with the digital auxiliary information. Application of this technique involves providing approximate digital archival for printed photographs. This enables scanning and reprinting from the printed photograph with improved quality many years later. The print and the associated digital auxiliary information assist in the reconstruction process. Our method enables archiving by combining on the same printed material both the photograph to be viewed as well as the digital auxiliary information described in this paper. This enables automatic archival whenever photographs are printed. The combination of the printed photo and the digital Auxiliary Information (AI) is called as PhotoPlus in [1]-[4] and [8]. The need for digital image recovery from the print – scan channel has been well discussed in the literature [6] and it is a fundamental task to recover images with improved quality. Encoding process extracts auxiliary information from the original digital image and decoding process uses it to remove the distortions as described in [1].

Extracted digital auxiliary information can be stored by printing it on the back or border of the printed photograph as suggested in [1] using invisible inks or dense barcodes [7], using Memory spot physical memory technology [9], and RFID's. The scope of this work does not include the storage mechanism used for digital auxiliary information; rather it assumes that digital auxiliary information can be accessed error free during decoding process. The amount of auxiliary information used is also need to be minimized while providing adequate accuracy for reprinting and recovery from the original print.

The scanning process introduces the following main distortions 1. Registration Errors 2. Color Errors. The extracted auxiliary information must include components to eliminate the above distortions. Registration errors introduced during scanning process are eliminated by using very small amount of auxiliary information. Color errors are eliminated by using the remaining auxiliary information. Details about the digital auxiliary information extracted during encoding process and the reconstruction techniques used during decoding are described in the following sections. Section 2 describes the extraction of digital auxiliary information. Section 3 describes the reconstruction methods that provides image registration and color correction. Section 4 reports the experimental results that show both quality improvements, reduced digital storage and also increased PSNR.

II. Encoding

This process is used to extract digital auxiliary information. It includes two major steps. First step extracts auxiliary information for correcting registration errors and the second step extracts auxiliary information for correcting color errors. The proposed encoding technique is completely different and it is very efficient when compared to the technique proposed in [1], [5], [7] and [8] in terms of space requirements and quality of decoding..

A. Registration

During PhotoPlus encoding the input image M X N, the actual size of the input image (includes number of rows and number of columns) are extracted and it is found to be sufficient for aligning the scanned image with the original digital image. The number of rows and columns of the original digital image is transmitted in order to determine the required horizontal and vertical resampling factors for the scanned image. Figure 1 shows the overall system flowchart of our proposed approach and it is self explanatory.

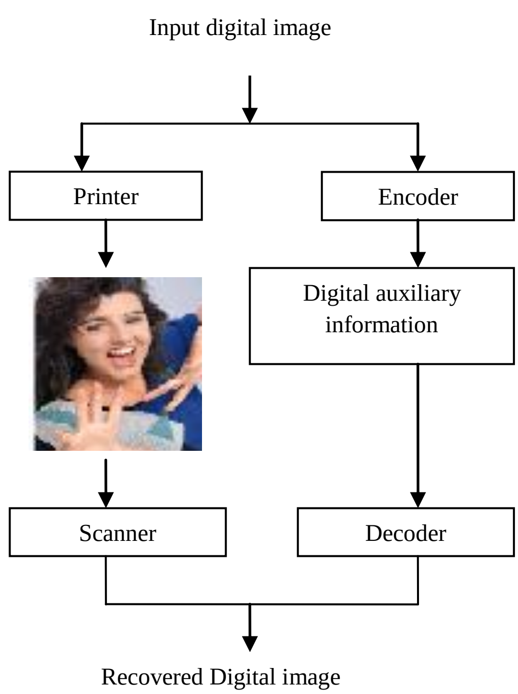

Fig. 1: Overall System flow chart

B. Color Correction

During PhotoPlus encoding of the input RGB image, to obtain a representative set of colors, the image is first divided into non-overlapping blocks and several color values together with their locations are sampled from each block. Based on the original input image size each block has P X Q pixels. The first step in obtaining color samples from each block is to find the variance of every pixel in the block and choose the pixel which has the least variance with their neighborhood pixels. The selected pixels row and column information and their corresponding RGB color value comprise the auxiliary information for color correction. The auxiliary information extracted for color correction also include another color sample for every block other than the less variance one and which is selected randomly.

III. Decoding

Decoding process contains two steps. The first step uses registration auxiliary information composed of size of the original digital image to register the scanned image and the second step uses color correction auxiliary information composed of selected color pixel values and their locations to color correct the scanned image.

A. Registration

During PhotoPlus decoding, the blocks of the input image are matched against the warped printed and scanned photograph. The scan is assumed to be of an appropriately high-resolution. An optimization finds the parameters of the matching transformation constrained to be a 2-D, eight parameter projective remapping that remaps the scanned image into an image with the same dimensions (row and columns) as the input image.

Specifically, if the original input image is of size M X N and the four corners of the scanned image are at the location (x_0,x_1),(x_2,x_3), (x_4,x_5) and (x_6,x_7) are respectively for top-left, top-right, bottom-left and bottom-right corners. Then the original digital pixel (0,0) maps to (x_0,x_1) in the scan , (0,N-1) maps to (x_2,x_3), (M-1,0) maps to (x_4,x_5) and (M-1,N-1) maps to (x_6,x_7).

These conditions yield a unique projective transformation $\mathbf{T_x}\{\ \}$ with $x=(x_0,x_1, x_2,x_3, x_4,x_5, x_6,x_7)$ that maps an original image pixel (i, j) to the corresponding scanned image pixel (i_s, j_s).

Transformation is given by

$$(i_s,j_s)= \mathbf{T_x}\{(i, j)\} \qquad (3.1)$$

where

(i_s, j_s) is scanned image pixel
(i, j) is the original pixel
$\mathbf{T_x}$ is the Projective Transformation function

B. Color Correction

During PhotoPlus decoding, the color reconstruction must correct for the printing and scanning color distortions, approximately transforming all of the scanned image colors to the original input image colors. A two stage process is used to recover the color information. The first stage applies a 1-D polynomial lookup tables followed by a multivariate polynomial approximation to smoothly fit the colors. The polynomial modeling is used instead so that a relatively small number of color samples fully models the print-scan channel. In addition, for our application, the exact input image color values are known for the colors extracted during PhotoPlus encoding. The result from the first color correction stage, with the polynomial modeling, does not necessarily interpolate these known values accurately. To correct for this, the color residuals from the first stage pass through the second stage which applies a reconstruction matrix (RM) to generate the final approximated color.

Let IC=(r, g, b) ^{T} is the original color for one input image pixel sampled during PhotoPlus encoding. After printing, scanning and registration but before color correction, the distorted Scanned Color (SC) is given by SC= $(r_s, g_s, b_s)^T$. There will be a total of N_s sampled colors that can be used to aid the color correction. During color correction, first a monotonically increasing third order polynomial (1-D table) is applied independently to each color component of the registered scan colors. The SC polynomial is denoted by

$$p(x)=p_0+p_1\mathbf{x}+p_2\mathbf{x}^2+p_3\mathbf{x}^3 \qquad (3.2)$$

Where **x** represents a color (vector) component of SC. Applying these polynomial results in the modified color MC= $(r^1, g^1, b^1)^T$ where

$$\begin{pmatrix} r^1 \\ g^1 \\ b^1 \end{pmatrix} = \begin{pmatrix} p(r_s) \\ p(g_s) \\ p(b_s) \end{pmatrix} \qquad (3.3)$$

Next the nine terms

$(r^1, g^1, b^1, r^1 g^1, r^1 b^1, g^1 b^1, (r^1)^2, (g^1)^2, (b^1)^2)$ are used to generate a nine component vector V

To this vector a matrix RM is applied to form estimate RC it is given by

$$RC= RM * V \qquad (3.4)$$

RC is the estimate of original color IC after the second approximation step of color correction. A nonlinear minimization procedure is used to find the four coefficients of p(x) and the 27 elements of RM such that it minimizes the expected error between C and RC.

The chosen color correction auxiliary information, the coefficients of the chosen polynomial and the elements of matrix R plays a major role in minimizing the distortions between the reconstructed color value and the original color value for every pixel..

IV. Results And Discussions

We implemented a digital image recovery system to recover digital images from printed photographs with improved accuracy which extracts the digital auxiliary information during the process of encoding and subsequently reconstruct the scanned images in the process of decoding. Several photographic prints of varying sizes are used for testing accuracy of reconstructed image. The extracted auxiliary information by our technique includes the row and column location of the original digital image and sampled color pixel values and their corresponding locations to reduce registration distortions and color distortions as described in section 2. The scope of this work does not deal with the storage mechanism of the digital auxiliary information. A HP Scan Jet 2400 scanner is used to scan the printed hardcopies at the resolution of 600dpi. As a first step encoding process extracts the digital auxiliary information from the original digital image comprising of size and some sampled color pixel values and their locations. In the second step, the extracted registration auxiliary information i.e., the size of the input image is used to correct registration errors and aligns the scanned image with the original digital image. The resulting registered image is used to aid the color correction process. After that for correcting color errors extracted color pixels and their locations are used and all the pixels are color corrected in block by block basis. The resulting registered and color corrected image is the approximated image of our digital image recovery system. Figure 2 shows the result of implemented digital image recovery system for lena image. Figure 3 shows the result of digital image recovery for Chart image by the implemented system and finally Figure 4 shows the result for Saroja image recovered by the implemented system. In all the above mentioned figures Figure 2, 3 and 4 (a) denotes the original image (b) denotes the scanned image (c) denotes the recovered image by the proposed digital image recovery system.

TABLE I

PERFORMANCE EVALUATION: COMPARISON OF PSNR OF VARIOUS IMAGES WITH VARYING BLOCK SIZES.

Block size	Lena image (PSNR) in decibels	Chart image (PSNR) in decibels	Saroja image (PSNR) in
2 x2	37.8	32.7	36.2
4 X 4	33.7	30.2	34.2
8 X 8	30.9	29.1	32.9
16 X	29.6	28.4	29.8
32	27.4	27.1	27.7
64 X 64	24.2	26.3	26.5

Table I shows the result of computed PSNR for various images with varying block sizes.

- From the data, it can be seen that images with large smooth regions like Lena image and Saroja image has the highest PSNR. This is because of the presence of less variance deviations in those images.

- On the other hand, the PSNR values of the images highly depend on the block size chosen. If the amount of Auxiliary information extracted gets increased then the PSNR value of the approximated image also gets improved.
- The quality of the approximated image highly depends on the amount of auxiliary information extracted for that image and the block size chosen.

TABLE II

AMOUNT OF AUXILIARY INFORMATION EXTRACTED FOR VARIOUS IMAGES WITH VARYING BLOCK SIZES.

Block size	Auxiliary Information Required (in Kilo Bytes)		
	Lena Image	Chart Image	Saroja Image
2 X 2	49	30	38
4 X 4	12	7.5	10.6
8 X 8	3	1.8	2.4
16 X 16	0.7	0.4	0.5
32 X 32	0.1	0.1	0.1
64 X 64	0.08	0.06	0.07

(a) **(b)** **(c)**

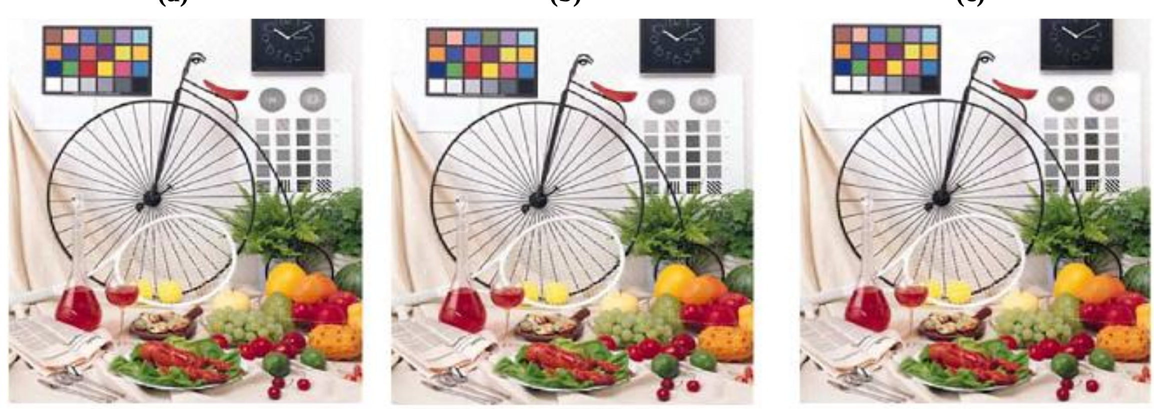

Fig. 3. Results of registered and color corrected process for Chart image (a) Original image (b) Scanned image (c) Recovered image

Fig. 4 Results of registered and color corrected process for Saroja image (a) Original image (b) Scanned image (c) Recovered image

Table II shows the amount of auxiliary information extracted for varying block sizes.

The following points can be drawn by comparing the performance of the implemented digital image recovery system.

- It can be clearly seen that the increase in block size results in increasing amount of auxiliary information required for approximation. It is because that the number of pixels extracted highly depends on the block size.
- The amount of auxiliary information extracted also highly depends on the size of the images.
- Since, the proposed technique choose a less variance pixel and a random pixel other than the selected one (i.e.) totally of two pixels per block. Thus the amount of extracted auxiliary information highly depends up on the block size.

Figure 5 and 6 show the overall PSNR computed for Lena and Chart image and it is compared against the various existing techniques. The overall PSNR values are computed by combining the combined mean square error for each color components. Thus the corresponding plot show the performance gains of the proposed technique in comparison with the Wyner-Ziv encoder, regular encoder, JPEG 2000 and baseline JPEG.

These comparison results suggest that the fidelity of the approximated images by the proposed method is better than those by the other existing methods such as WZ-1 channel coded bit plane method, Regular block entropy encoder, JPEG 2000 and baseline-JPEG.

V. Conclusion

A new technique for improving quality of digital images in the print- scan channel is presented. It takes in to account that in order to make the size of scanned image as the original image and to correct registration errors projective transformation is used. Auxiliary information for registration correction includes the size of the original digital image.

A method is proposed for color correction includes selecting pixels from the regions where colors are changing very slowly, this ensures that color pixels are sampled from smooth regions. Thus it reduces color errors and color corrects the scanned image. The technique is proposed in such a way that it minimizes the amount of auxiliary information stored while maintaining accurate fidelity in image reconstruction. The image fidelity was measured and compared against original image using measures such as MSE and PSNR.

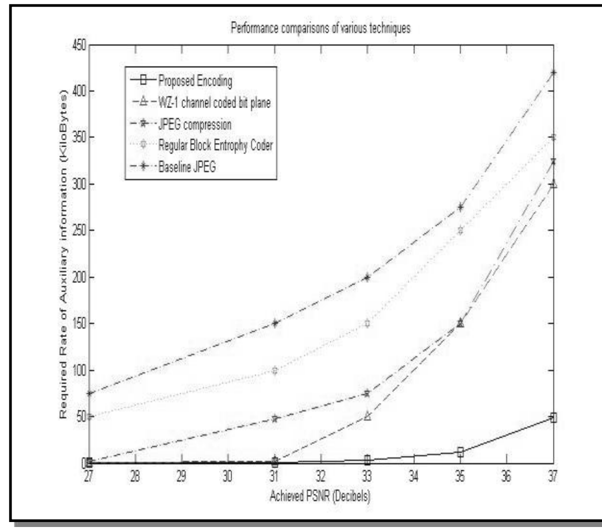

Fig. 5. Comparison of PSNR for Lena image of proposed technique against existing schemes

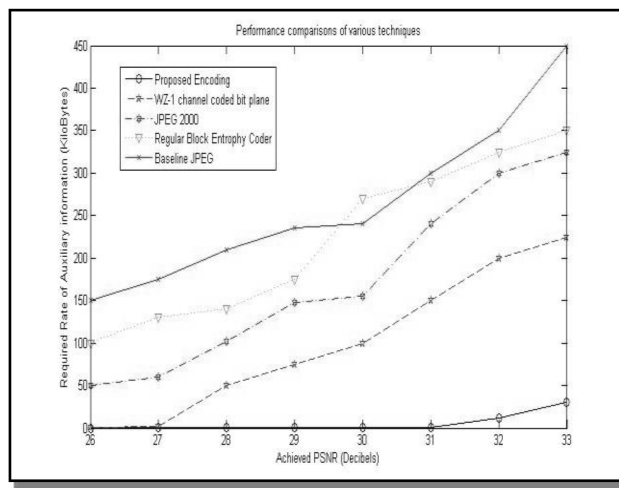

Fig. 6. Comparison of PSNR for Chart image of proposed technique against existing schemes

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