

# Discrete Topological Derivative Based Show-Through Noise Reduction in Scanned Document Images

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**Abstract** - The interdisciplinary approach of fusing ideas from different domains with an objective of optimized results is a recent trend in the research areas of image processing. One such attempt was experimented in this study by combining structural mechanics concept of Discrete Topological Derivative (DTD) with Otsu binarization method to remove the show-through existing in the scanned document images. The Otsu binarization method was chosen through a comparative study with other traditional binarization method. The proposed method DTD-cum-Otsu was implemented in scanned document images and compared with other six state-of-the-art techniques such as Wiener, Bilateral, Median, Gabor, Homomorphic and Perona-Malik. The algorithms developed for the proposed study was tested in more than 150 scanned document images collected from the databases viz., DIBCO2013, DIBCO2014 and Nabuco dataset-2 and classified into three groups such as lightly-affected (LA), moderately-affected (MA) and strongly-affected (SA) show-through noisy images. The effectiveness of the proposed DTD-cum-Otsu method was assessed through visual inspection and quality metrics like PSNR, MSE, NAE, NCC, AD, F-measure, pseudo-F-measure, DRD, NRM and MPM. The results of this study reveal that the proposed method is the optimum technique to remove the show-through noise effectively and retaining the useful information without distortion. Further, the execution speed of the proposed method is within the range of real-time application requirements. Thus, the outcome of this study exhibits the glimpse of hope on the multidisciplinary approach of solving potential real-life problems.

**Key Words:** Show-through, Binarization, Image denoising, Diffusion, image enhancement, Quality metrics, DTD, Otsu.

## 1. INTRODUCTION

In recent years, most of the important documents are being converted into digital formats for preserving them from aging, mutilation, spoilage, accidental damages, etc. Further, these scanned documents in the digital format have several advantages like security through encapsulation, e-exchange via digital communication, future reference through archiving, e-verification using authentication, etc. These records include ancient historical documents, government/official documents, ancient palm leaves collections, medical hints, etc., which bring lot of useful

information to realize our history, culture, language, evolution of society, and many more [1]. During the digitization process, the scanned digital data contains various types of noises such as margin noise, ruled line noise, clutter noise, non-uniform illumination noise, uneven contrast, interfering strokes, background spots, show-through effect etc. These noises will affect the quality of the document image as well as readability [2]. Among these noises, the show-through noise is one of the major artifacts that affects the quality and readability of the document. Therefore, these noises should be removed without the loss of details in the scanned original documents. Show-through effect is one of the document image noises which present during the document digitization process due to document ageing, ink seepage, thickness/quality of the paper, and scanning device. In a scanner, when the single side printed/handwritten document is scanned, the light exposes to the paper transmits through the document medium and reflects back by the backing of the scanner. The reflected light receives the front-side information by the detector and sent for the display and storage section. But, in the case of double-side printed document scanning, the back-side of the document information merges with the front-side of the document information is known as 'show-through' or 'bleed-through' or 'back-to-front interference' [3]. This interference makes the reader uncomfortable in understanding and complexities in further processing tasks like automatic character recognition. Several denoising and binarization techniques were investigated by many researchers for removing the document degradations from scanner or camera captured images. Various image enhancement techniques such as non-registration [4, 5], registration-based [6, 7], histogram-based [8], thresholding-based [9-11], Genetic algorithm-based [12], and wavelet-based filtering [13] had been implemented to ameliorate the quality and readability of the scanned document images. Still this issue is prevailing as a challenging task and researchers in this area have been endeavoring with multidisciplinary approach of transforming the mathematical ideas established in other fields to solve this kind of document image processing tasks. As a consequence of this effort, a novel structural mechanics concept namely, discrete topological derivative (DTD) was experimented in this research paper for filtering the show-through noise in combination with a binarization technique to enhance the quality and readability of the scanned document images.

Recently, many researchers have contributed to the Partial Differential Equation (PDE) based methods for solving the image degradation in document image processing, including diffusion like PDE's for image filtering, shock filters for image deblurring and level-set approach for image segmentation. To overcome the shortcomings of the traditional threshold method, Wang and He [14] introduced an evolution PDE-based binarization technique to improve the quality of camera-captured document images. A method based on the dynamic diffusion-based model coupled with a nonlinear Fitzhugh-Nagumo type source term, which demonstrated better character recognition [15], [16]. A nonlinear diffusion equation with an adaptive source term exhibited noticeable smoothing with preservation of details and the desirable binarization properties was experimented by Guo et al. [17]. Subsequently, they exploiting an adaptive enhancement scheme [18] involving a shock filtering and nonlinear isotropic diffusion terms for improving the degraded document images. Zhang et al. [19] developed a modified form of Perona-Malik [20] anisotropic equation using parallel-series splitting algorithm by combining finite differencing with two kinds of splitting methods for the binarization of bleed-through document images. For the purpose of restoring damaged document images, Du and He provided an anisotropic diffusion equation with a selective source [21] followed by a basic global thresholding. Recently, they introduced an anisotropic diffusion model with fuzzy-based source for separating the foreground from background of the degraded images [22]. Drira et al. presented a tensor based Weickert coherence-enhancing diffusion non-linear filter for controlling the diffusion process to preserve the edge and corner information of the document images [23, 24]. Mahani et al. proposed the application of PDE based methods to deduce the reflectance from the log of luminance and demonstrated the improvements in the images acquired using low-quality camera phone images [25]. The aforementioned PDE based methods was inspired by some anisotropy diffusion process in the document image reconstruction. But, none of the above reviewed literature tried any novel methods from innovative concepts adapted from other fields. This paper aims to unravel the potentiality of a structural mechanics approach, called discrete topological derivative filter with binarization technique to remove the show-through effect and conformed its capabilities through a comparative study with six other traditional techniques. Further, a study was conducted among six binarization techniques and the outcome of this study was used to identify the Otsu technique as an optimum method for the binarization of document images. Finally, each of the six different denoising filters was combined with the Otsu binarization technique and studied the performance of the filters in terms of visual perception and quality metrics.

The remaining parts of the paper are sub-divided into following sections: the theory of topological derivative, concept of discrete topological derivative filter and binarization methods are described in Section 2, followed by

the algorithm development steps of the proposed methods in Section 3, and the experimental results and inferences are exemplified in Section 4. Finally, the concluding remarks of this study are summarized in Section 5.

## 2. TOPOLOGICAL DERIVATIVE

Topological derivative is used to measure the shape sensitivity of a problem, when the domain  $\Omega$  is perturbed in some way. The perturbation may be change in topology (by the introduction of hole, crack, source term, inclusion etc.) or by change in material properties (diffusion coefficient that define the variations associated to the problem or change in the forces/source term). In the figure 1,  $\Omega$  is the domain perturbed by small hole (change in topology),  $\gamma_\epsilon$  is the crack of length  $\epsilon$  centered at the pixel  $n$ , and  $\Phi(\Omega)$  and  $\Phi_\epsilon(\Omega \setminus \gamma_\epsilon)$  are the cost function before and after perturbation, respectively. Hence,  $\Omega$  be a bounded open set in  $\mathbb{R}^N(N=2,3)$  and  $\gamma_\epsilon$  be the crack of length  $\epsilon$  centered at point  $\hat{x} \in \Omega$ . Therefore, cost function after perturbation can be defined as,

$$\Phi_\epsilon(\Omega_\epsilon) = \Phi(\Omega) + f(\epsilon)D_T(\hat{x}) + o(f(\epsilon)) \dots \dots \dots (1)$$

where  $f(\epsilon)$  is a positive function tend to zero with respect to  $\epsilon$  value, and  $D_T(\hat{x})$  is the topological derivative at the point  $\hat{x}$ . By applying the perturbation at the point  $\hat{x}$  having  $D_T$  of negative value, the cost function  $\Phi$  will be reduced, since  $f(\epsilon)$  is positive.

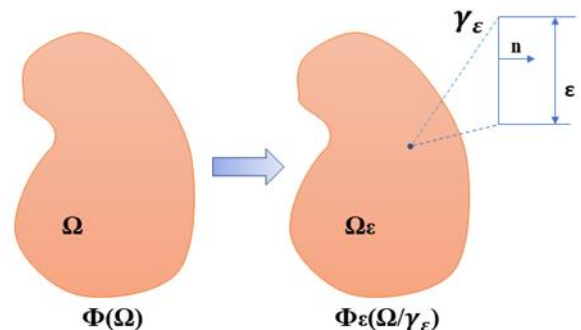


Fig. 1: The diagrammatic representation of topological derivative concept

Thus,  $D_T$  decides the best places where the perturbation will be applied to reduce the cost function value, since it measures the degree of similarity between two images with the limit  $\epsilon \rightarrow 0$ , therefore the eqn.(1) is divided by  $f(\epsilon)$  which provides the eqn.(2) [26].

$$D_T \hat{x} = \lim(\epsilon \rightarrow 0) \Phi_\epsilon(\Omega \setminus \gamma_\epsilon) - \Phi(\Omega) / f(\epsilon) \dots (2)$$

$$\Phi_\epsilon(\Omega \setminus \gamma_\epsilon) = \Phi(\Omega) + f(\epsilon)D_T(\hat{x}) \dots (3)$$

In this paper, this discrete topological derivative is employed as a function to separate the background and foreground information, which ultimately reduces the show-through noise from scanned document images. Thus, it serves as a restoration filter to denoise the show-through effect. Then, a global binarization was applied to exhibit the effect of

preserving the foreground information from the background interference by the proposed method.

### 2.1 Discrete Topological Derivative

The Discrete topological derivative (DTD) method is employed in this work, which utilizes a cost function and its discrete form, is denoted by the eqn. (4).

$$\Phi(x_i^s) = \sum_s \sum_{p \in n^s} k^{s,p} \hat{\Delta} x_i^{s,p} \cdot \hat{\Delta} x_i^{s,p} \dots (4)$$

where  $k^{s,p}$  is the diffusion of pixel  $s$  with its neighbors  $p$  having four pixels in the directions denoted by  $n^s = \{w, e, n, s\}$  and  $x_i^s$  denotes the intensity of the pixel. The discrete form of the  $\hat{\Delta} x_i^{s,p}$  is defined in the eqn. (5)

$$\hat{\Delta} x_i^{s,p} = x_i^p - x_i^s \dots (5)$$

The value of  $x_i^s$  is specifically estimated using the eqn. (6)

$$x_i^s(k^s) = x_{i-1}^s + \Delta t \sum_{p \in n^s} k^{s,p} \hat{\Delta} x_{i-1}^{s,p} \dots (6)$$

where  $i \geq 1$  is the iteration number,  $k^s = \{k^{s,w}, k^{s,e}, k^{s,n}, k^{s,s}\}$  is the four diffusion coefficient associated with the neighbouring pixels of  $s$  and  $\Delta t$  is the size of the time-step.

Let us apply perturbation at the pixel  $s$  (with the adjacent pixels  $p$ ) having an initial value of  $k^{s,p} = 0$ . The specific function  $x_i^s$  having a set  $k^s$  and its best diffusion values can be estimated from the specific function  $x_i^s$ , which tunes the cost-function in such a way to identify the details to reduce the show-through noise of the document image. Thus, the cost functional's total variation with respect to the perturbation in  $k^{s,p}$  can be computed using the eqn. (7).

$$\Phi(x_i^s(k_\epsilon^s)) = \Phi(x_i^s(k^s)) + D_T(s, k_\epsilon^s) \dots (7)$$

where  $D_T(s, k_\epsilon^s)$  represents the total variation of the cost functional due to perturbation on the diffusivity coefficient at pixel  $s$  characterized by the set  $k_\epsilon^s$ . In this work, let  $k_\epsilon^s \in \{0, k_0\}$ , then the set of all possible values of  $k^s$  can be defined by the eqn. (8)

$$C(s) := \left\{ k^s = (k^{s,w}, k^{s,e}, k^{s,n}, k^{s,s}); k^{s,p} \in \{0, k_0\}, \right. \\ \left. p = \{w, e, n, s\} \right\} \dots (8)$$

From the Eq. (8), it is clear that 16 different values of  $k^s$  can be estimated using the neighboring four pixels, which has two values viz.,  $k^{s,p} = 0$  or  $k^{s,p} = k_0$  ( $2^4=16$  values). But, the cost functional value of all zeros can be discarded and hence the remaining 15 values are available. Of the 15 values, one value belong to the combination  $k_{iso}^s = (k_0, k_0, k_0, k_0)$  denoted by the parameter  $C_\sigma$  may be discarded owing to its non-perturbed and isotropic nature. As a result, the remaining 14 combinations are represented by the parameter  $C(s)$ .

Therefore, the  $D_T$  value of any pixel can be computed by perturbing that pixel  $s$  having combination of  $k_\epsilon^s \in C_\sigma$ . The cost function  $\Phi_\epsilon(x_i^s)$  becomes,

$$\Phi_\epsilon(x_i^s) = \Phi(x_i^s) - \sum_{p \in n^s} k^{s,p} \hat{\Delta} x_i^{s,p} \cdot \hat{\Delta} x_i^{s,p} \dots (9)$$

Suppose  $\epsilon x_i^s = x_i^s(k_\epsilon^s)$  and  $x_i^s = x_i^s(k_{iso}^s)$ , then using eqn. (6), we can acquire the value  $\hat{\Delta} \epsilon x_i^{s,p} = x_i^p - \epsilon x_i^s$ . From the eqns. (7) and (9), the total variation of the cost functional  $\Phi$  due to the perturbation  $k_\epsilon^s$  can be written as

$$D_T(s, k_\epsilon^s) = \sum_{p \in n^s} k_\epsilon^{s,p} \epsilon x_i^{s,p} \cdot \epsilon x_i^{s,p} - \sum_{p \in n^s} k^{s,p} \hat{\Delta} x_i^{s,p} \cdot \hat{\Delta} x_i^{s,p} \dots (10)$$

The equation 10 is used to develop the algorithm of discrete topological derivative for denoising the show-through effect from document images. Selecting the correct cost function based on the particular image is a challenging task for removing the noise effect in a lucient manner. In this paper, we have chosen the cost function introduced by Larrabide et al. [27] and applied the same to study the capabilities of the proposed algorithm in removing the show-through effect from the degraded document images. By selecting the cost function between 0 and 1 and the diffusion will stop at  $k=0$ , which gives the total variation in the cost function and hence the DTD filtering will come to end. The suitable selection of the pixel for perturbation and the computation of the related cost function will be of significant role in preserving the edges in the text regions of the document images.

### 2.2 Otsu's Binarization

Binarization is the process of converting gray scale intensities (0-255) to a binary level (0s and 1s). When the input pixel intensity is compared with threshold T value, the corresponding output pixel intensity is changed to 0s and 1s according to greater than or less than or equal to the threshold value T. Otsu's approach of the optimal threshold selection based on the discriminant criterion by the integration of the histogram. The two options for threshold selection is to minimize within-class variance  $\sigma_w^2(t)$ , or maximize the between-class variance  $\sigma_b^2$  and the equation can be written as,

$$\sigma_w^2(t) = w_1(t)\sigma_1^2(t) + w_2(t)\sigma_2^2(t) \dots (11)$$

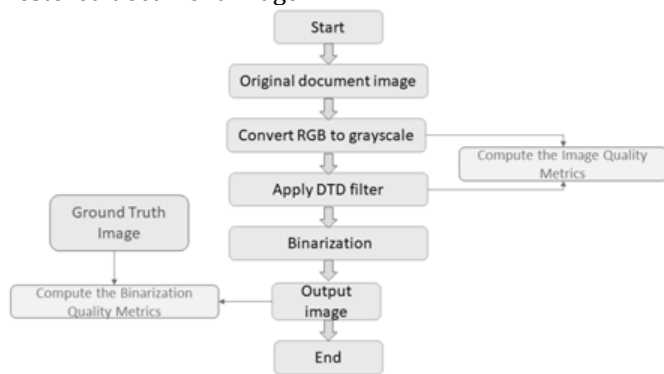
$$\sigma_b^2(t) = w_1(t)w_2(t)[\mu_1(t) - \mu_2(t)]^2 \dots (12)$$

where  $w_1(t)$  and  $w_2(t)$  are the probabilities of the two classes divided by a threshold  $t$ ,  $\mu_i$  is a mean of class  $i$  and  $\sigma_i$  is a variance of class  $i$ . After applying the DTD filter, the filtered image was binarized with Otsu's method [28] to exhibit the capabilities of denoising the show-through effect in document images.

### 3. PROPOSED METHOD

In this section, we present a discrete topological derivative (DTD) filter with Otsu binarization method for denoising of the show-through effect on document images. The flowchart of the proposed model is shown in figure. 2. The principal idea of this algorithm is to calculate the topological derivative for an appropriate cost functional introduced as perturbation in a pixel in order to identify its diffusion with the neighboring pixels. At this point, the topological

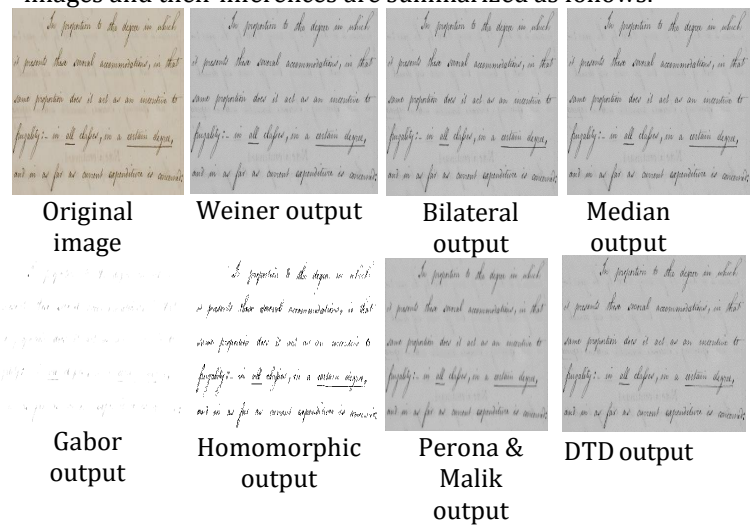
derivative acts as an indicator function to find the best pixels to introduce the perturbation that will reduce the show-through noise and preserve the text image characteristics. The original scanned document image is taken as an input. Before applying the DTD filter, the raw input image was converted into grayscale image. In this DTD algorithm, the input image is magnified to a single pixel level in order to apply the cost function to a single pixel. The single pixel identified for diffusion is now subjected to the cost function. For each of the 16 possible outcomes, the diffusion coefficient of the applied cost function is determined (under the assumption that the affected pixel is surrounded by four nearby pixels). At this point, the topological derivative is set as an indicator function to determine how much the cost function has varied overall. Next, the tolerance value, which will always be fixed at a value greater than zero, is compared to the cost function of the first iteration. The iteration is stopped if the cost function is smaller than the tolerance value; otherwise, it continues to calculate the new cost function value by using a different value of the diffusion coefficient. The gradient for the new image and the old image is calculated for sensitivity analysis, if iteration is paused. The denoised image is then reshaped using the topological derivative value. This process is repeated for each pixel in the image. Then, the Otsu's binarization is applied to the restored document image.



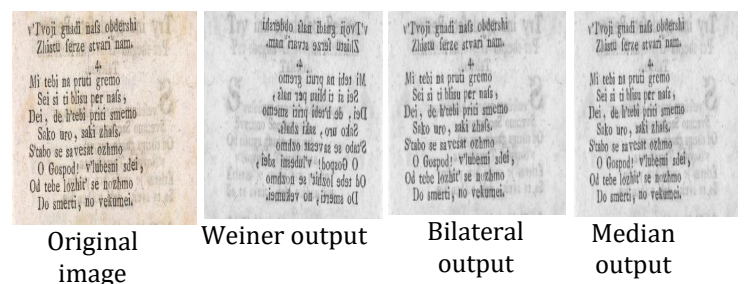
#### 4. EXPERIMENTAL RESULTS

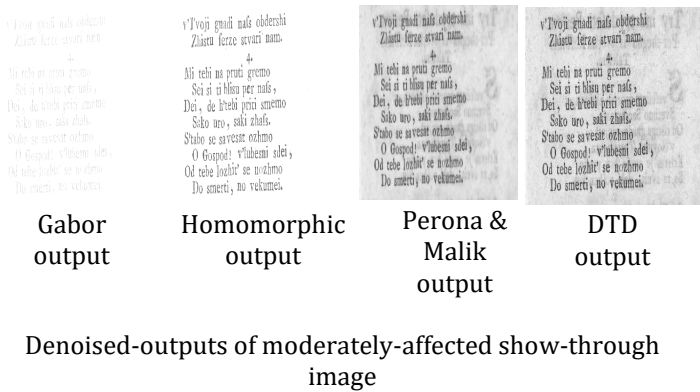
In this section, the proposed method was tested on more than 150 document images collected from databases such as DIBCO 2013, DIBCO 2014 and Nabuco dataset-2. The input images were categorized into lightly-affected, moderately-affected and strongly-affected show-through noisy images, which were selected for testing the proposed algorithm. The results obtained for the proposed DTD method were compared with the traditional denoising filters such as Weiner, Median, Gabor, Homomorphic, Bilateral, and Perona & Malik filter. To identify an optimum binarization method for a clear visualization of the denoised image, Otsu, Niblack, Feng, Wolf, Kapur, Kittler and Sauvola [29] binarization methods were tested on the raw images and computed their performances both quantitatively and qualitatively. From the datasets, we have chosen three types of sample show-through-affected (lightly, moderate, strongly) images and their respective ground truth images for evaluation. To

assess the DTD filter performances with the other five denoising filters, Peak-Signal to Noise-Ratio (PSNR), Average Difference (AD), Normalized Absolute Error (NAE) and Normalized Cross Correlation (NCC) parameters are estimated. For the assessment of the performance of the filters, higher-PSNR, lower-MSE, lower-NAE, unity-NCC and lower-AD are recommended and employed for the interpretation of the results obtained. Further, the performance of the binarization as well as proposed DTD with Otsu methods were computed using F-measure (FM), pseudo-F-measure (p-FM), Distance Reciprocal Distortion (DRD), Negative Rate Metric (NRM) and Misclassified Penalty Metric (MPM) [30-33]. Here, higher F-measure, higher p-FM, lower DRD, lower NRM and lower MPM are considered as better standards for validating the results of the binarization and filtered-binarization techniques. These performance metrics are suited for the objective evaluation in the context of document image analysis and recognition. The proposed DTD method and other techniques were implemented on MATLAB (r2018a) compiler and run on an Intel core processor CPU 2.20 GHZ processor with 4.00 GB RAM and Windows 10 Operating system. The results of the case studies for the three different show-through-affected images and their inferences are summarized as follows.



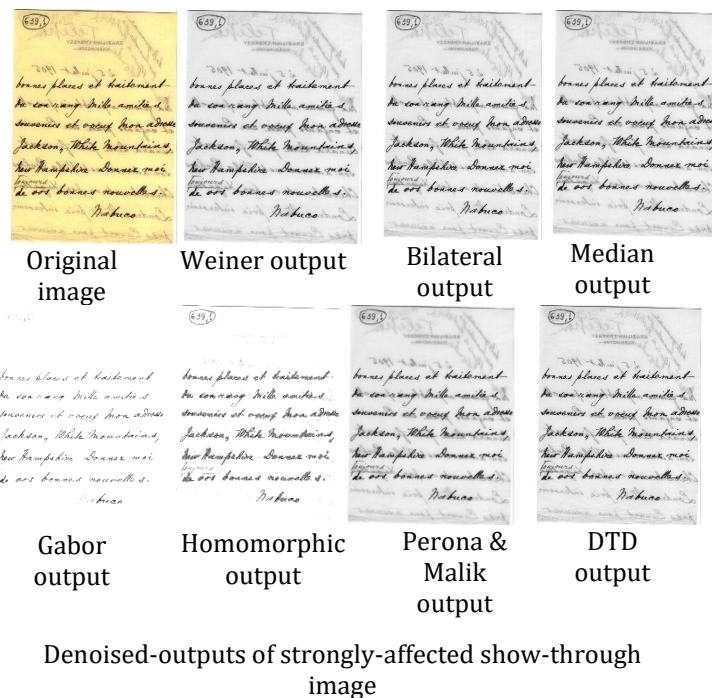
Denoised-Outputs of lightly-affected show-through image





	MA	2.6157	1.3102	2.0492	1.7516	0.9222	3.6895	0.6750
	SA	1.7271	0.7331	1.1182	1.8428	2.1888	2.6428	0.5114

Figure 3 and Table 1 are the denoised-output images for LA, MA and SA affected show-through noise images and their respective performance metrics, respectively. On visual inspection of images in the Figure 3, it is observed that the DTD filter retains the details of the LA image, but very little show-through noise with the background information are still present, whereas the Homomorphic and Gabor filtered images are looked like completely denoised outputs, which are the result of over-filtering of the details and background information in those images. The remaining four filters' outputs have comparatively less details and background information than the proposed DTD filter. From estimated performance metrics given in the Table 1, the proposed DTD filter has high PSNR, low MSE, low NAE, unity NCC and low-AD values than its visually better counterparts viz., Gabor and Homomorphic filters are concerned. This implied that the DTD filter optimally tunes the cost-function to remove the show-through noise at the optimum level than the other filter with maximum details as well as background information



In the case of MA image shown in Figure 3, the DTD filter performed well by retaining the details as well as the background information of the image by optimally-filtering the show-through noise. In the contrary, the Homomorphic filter completely removed the background information and finer details of the image which is exhibited as total-filtering of the show through noise. The Gabor filter lost most of the details and the background information and the other four filters are not on par with the proposed DTD results. These observations are ascertained from the performance metrics (Table 1) such as higher PSNR, lower MSE, low-NAE, unity NCC and lower AD values, which is better than visually clear Homomorphic filter image. Thus, the DTD filter is the better choice for the MA show-through noisy images.

**Fig.3:** Results of the denoising outputs of proposed DTD and other filters

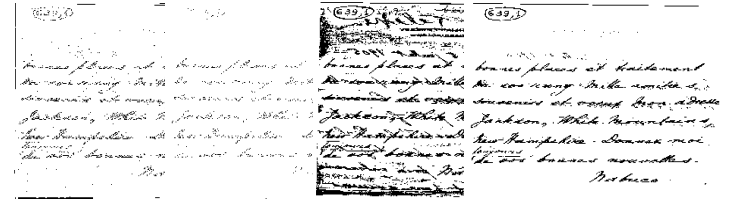
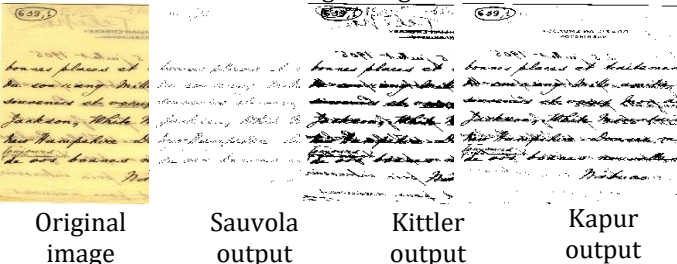
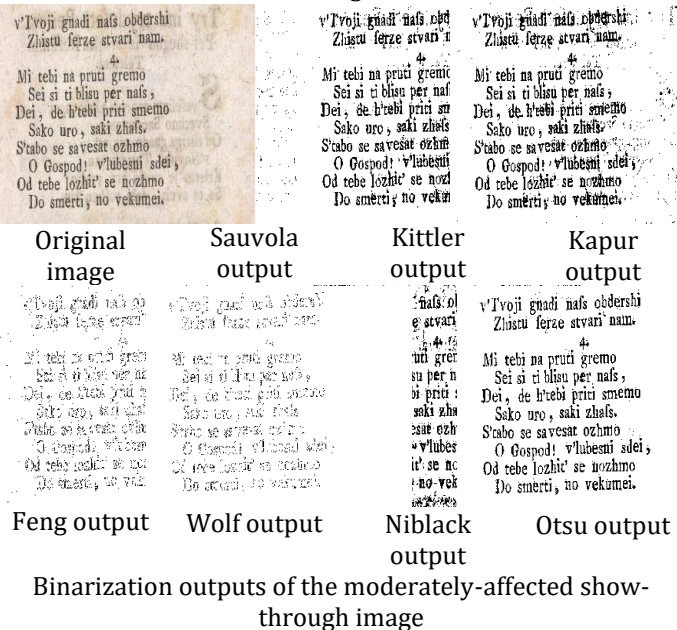
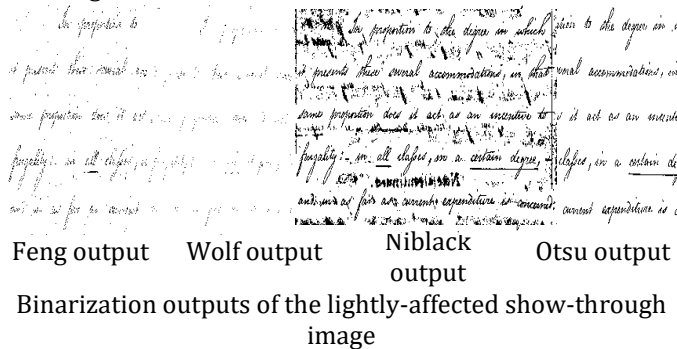
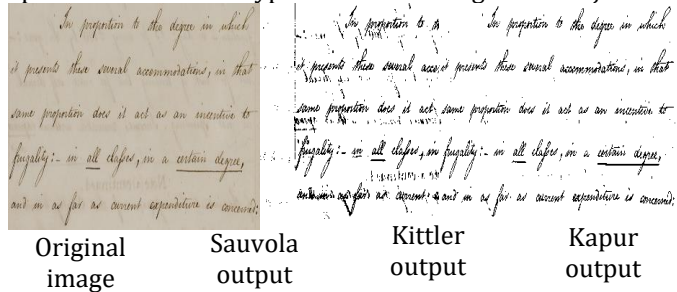
**Table 1:** Image quality metrics of the lightly-affected (LA), moderately-affected (MA) and strongly-affected (SA) show-through noise images of the proposed DTD and other six filters

Quality Measure	Type of image	Weiner	Bilateral	Median	Gabor	Homomorphic	Perona & Malik	DTD filter
PSNR	LA	43.2755	43.1942	44.1100	43.1618	43.3207	36.2159	43.9802
	MA	35.2212	40.4471	36.4709	43.1152	40.7283	32.9325	43.3023
	SA	37.7138	43.0844	40.1361	42.6599	38.7320	34.8548	43.1522
MSE	LA	3.0586	0.9855	14.6553	2.4940	2.4044	15.5412	2.6005
	MA	19.5417	5.8664	2.5240	3.1737	5.4985	33.1003	3.0399
	SA	11.0077	2.5381	6.3019	3.5244	8.7072	21.2618	3.1467
NAE	LA	0.0041	0.0019	0.0028	0.6831	0.0018	0.0097	0.0017
	MA	0.0126	0.0063	0.0099	0.6831	0.0038	0.0178	0.0033
	SA	0.0079	0.0034	0.0051	0.6831	0.0090	0.0121	0.0023
NCC	LA	1	1	1	0.3169	1.0002	1	1
	MA	1	1	1	0.3169	1.0001	1	1
	SA	1	1	1	0.3169	1.0042	1	1
AD	LA	0.7556	0.3480	0.5192	1.5708	0.4445	1.8040	0.3183

For the SA image shown in Figure 3, the DTD filter optimally enhances the foreground as well as the background information, while filtering the show-through noise to the required level for better visual perception. On the other hand, the Homomorphic filter seems to be better denoising at the cost of finer details of the foreground and maximum information of background. The Gabor filter still worst than the Homomorphic and the other filters have attenuated more fore-ground information than the proposed DTD filter. These impressions are realized through the comparison of performance metrics of the SA image given in Table 1. The proposed DTD filter has higher-PSNR, lower-MSE, lower-NAE, unity-NCC and lower-AD values than its counter-part filters like Homomorphic and Bilateral. Consequently, the DTD filter is the suitable filtering technique for SA show-through images.

From the three grades of show-through noise-affected images, the DTD filter performed well in all types of noisy images such as LA, MA and SA over the other filters, which is evident from visual inspection and performance metrics. Further, DTD adjust the cost-function values iteratively for

identifying the foreground from the background in an optimum way to give better performance over the other filters. As a result, the proposed DTD filter is found to be optimum filter for all types of show-through noise rejection.

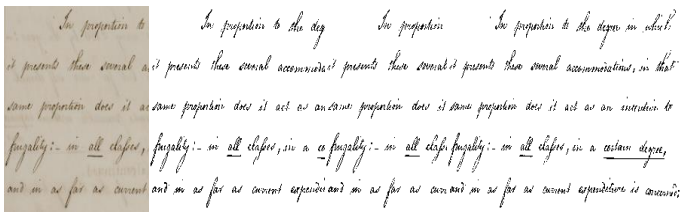


**Fig. 4:** Binarization outputs of the strongly-affected show-through image

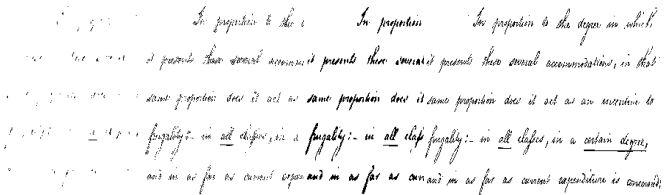
**Table 2:** Performance metrics of the seven binarization methods

Quality Measure	Type of image	Feng	Kapur	Wolf	Kittler	Niblack	Sauvola	Otsu
F-measure	LA	57.75899	93.094	16.84211	76.45143	55.47623	12.51691	89.1061
	MA	54.07624	85.65521	47.55058	87.97608	49.19254	17.31996	94.97196
	SA	64.0791	70.77617	47.2617	50.23836	38.8446	53.85396	85.50057
Pseudo F-measure	LA	28.67288	95.3596	1.57325	76.75204	56.10546	3.61614	95.69459
	MA	31.41438	85.93551	24.22539	88.40171	49.35547	7.08444	97.7011
	SA	52.98774	70.82064	19.26019	50.2402	38.85304	33.97732	85.51864
DRD	LA	10.8919	1.94128	15.43905	11.92975	33.463	15.64741	2.69777
	MA	7.5453	0.0063	15.93414	6.02454	53.88207	20.51179	1.71722
	SA	15.80976	18.7069	15.35724	46.92182	78.18367	13.81095	6.90756
NRM	LA	0.28959	0.02786	0.45399	0.02317	0.06515	0.46662	0.08979
	MA	0.30561	0.01979	0.34307	0.01825	0.10607	0.4526	0.03051
	SA	0.2008	0.02228	0.34249	0.05105	0.08146	0.31478	0.01088
MPM	LA	1.75188	0.67831	0.73001	13.14525	80.91008	0.70207	0.06549
	MA	2.08136	3.80042	0.47642	2.72243	163.8309	0.56402	0.14902
	SA	16.11097	13.20411	0.30586	41.24036	116.8652	0.39505	6.42423
PSNR	LA	14.54101	20.9705	12.86927	14.60863	10.58191	12.75964	19.42921
	MA	12.22146	15.27575	12.07593	16.17294	7.40118	10.91969	20.49733
	SA	14.72988	13.94898	14.62234	10.1401	8.13222	15.07727	17.82375

Figure 4 shows the binarization outputs of the familiar techniques used for the binarization of LA, MA and SA show-through noisy document images. The corresponding quality metrics estimated for the seven binarization methods are summarized in Table 2. From the visual inspection and the quality metrics the Otsu binarization technique is a best candidate for show-through noise affected document images. The Otsu method has scored higher PSNR, F-measure, and pseudo-F-measure values than the other six methods, which reflects its efficiency of precision and recall of the pixel information of the foreground from the background noise than the other methods. Further, the lower DRD, NRM and MPM values ascertained the proficiency of the Otsu method in extracting the foreground information from misclassification, precise boundary identification without or less distortion. Therefore, the Otsu method was chosen as the best binarization method for combining with the denoising filters to demonstrate the trustworthiness of the proposed DTD filter.

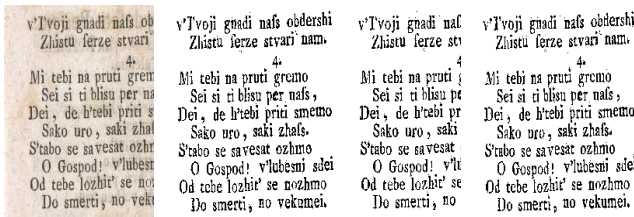


Original image      Weiner with Otsu      Bilateral with Otsu      Median with Otsu

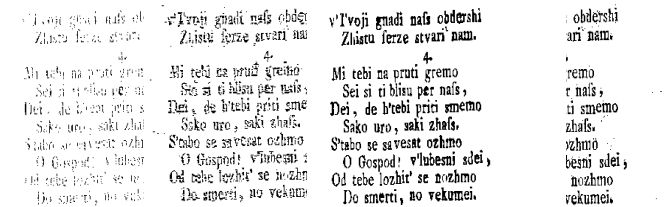


Gabor with Otsu      Homomorphic with Otsu      Perona & Malik with Otsu      Proposed method

Outputs of the denoising filter combined with Otsu binarization method for the LA show-through noisy image

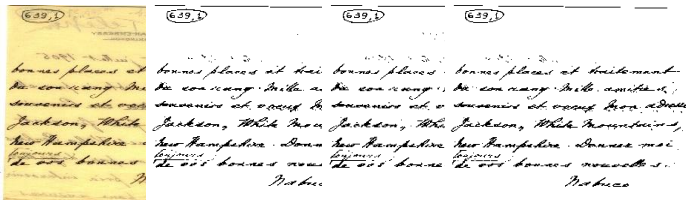


Original image      Weiner with Otsu      Bilateral with Otsu      Median with Otsu



Gabor with Otsu      Homomorphic with Otsu      Perona & Malik with Otsu      Proposed method

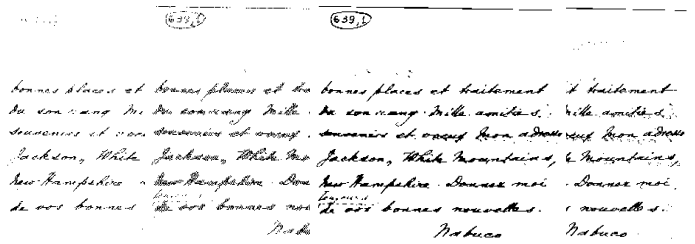
Outputs of the denoising filter combined with Otsu binarization method for the MA show-through noisy image



Original image      Weiner with Otsu      Bilateral with Otsu      Median with Otsu



Gabor with Otsu      Homomorphic with Otsu      Perona & Malik with Otsu      Proposed method



Gabor with Otsu      Homomorphic with Otsu      Perona & Malik with Otsu      Proposed method

Outputs of the denoising filter combined with Otsu binarization method for the SA show-through noisy image

Fig.5: Outputs of denoising filter with Otsu binarization method

Table 3: Performance metrics of denoising filter with Otsu binarization method

Quality Measure	Type of image	Weiner + Otsu	Bilateral + Otsu	Median + Otsu	Gabor + Otsu	Homomorphic + Otsu	Perona & Malik + Otsu	Proposed Method (DTD+ Otsu)
F-measure	LA	85.91484	87.80389	84.63832	14.85353	61.3654	76.30214	89.17744
	MA	95.42164	95.04987	95.71459	43.40843	74.0278	91.23257	94.38765
	SA	87.64266	87.91959	84.83698	77.51823	65.58946	85.38173	88.10037
Pseudo F-measure	LA	90.16916	93.42067	87.63366	16.69233	68.33733	75.95746	95.35961
	MA	97.22491	97.43546	97.41802	68.05305	82.20632	92.7744	97.81509
	SA	87.49344	87.89864	84.73697	89.14792	67.54376	84.9642	88.33235
DRD	LA	3.53604	3.01647	3.74661	15.13342	9.91637	7.23598	2.70279
	MA	1.48967	1.57653	1.52862	15.09141	9.31083	3.15246	1.88765
	SA	5.22897	5.46059	6.74772	6.11842	14.29446	6.40268	5.56368
NRM	LA	0.11332	0.10261	0.11677	0.45989	0.25745	0.10401	0.09268
	SA	0.02201	0.03581	0.0343	0.36139	0.18024	0.02732	0.03728
MPM (x1000)	LA	0.10541	0.07284	0.15539	0.6361	0.50584	0.47884	0.6121
	SA	0.04231	0.0615	0.05571	0.31126	0.7057	0.1011	0.12788
PSNR	LA	18.40897	19.01442	17.99942	12.82306	14.54141	15.43814	19.49485
	MA	20.8425	20.62462	20.30534	11.90139	13.90179	17.83388	20.05733
	SA	18.64194	18.74185	17.64684	17.45965	14.68944	17.83524	18.84044

Figure 5 illustrates the output images of the proposed DTD and other six standard filters combined with Otsu binarization method. The estimated quality metrics of all the filters cum Otsu binarization method are abridged in Table 3. From the Figure 5, the proposed DTD cum Otsu method results in clear foreground images without any noticeable loss in details of all the three types of show-through noise affected document images. Further, the edge and corner of the text are well-preserved in the proposed method than the others. The stroke and the style of the texts in the foreground are retained as such with out much distortion by attenuating the background information appropriately. These findings are substantiated by the quality metrics in terms of higher PSNR, F-measure and Pseudo F-measure values and lower DRM, NRM and MPM values. Further, each of the comparison filtering-cum-binarization method

behaved differently for the three types of show-through noisy images, whereas the proposed DTD method provide uniform performance which proved its trustworthy and effectiveness in denoising the show-noise. Thus, the proposed DTD-cum-Otsu method is a potential denoising method for removing the show-through noise present in the document binary images. Finally, the proposed algorithm took the execution time of around 7-11 s for all the three types of show-through noisy images without resizing their original size. This gives some hope in employing the proposed method for real-time applications.

## 5. CONCLUSION

This paper presents a new approach for enhancing the quality of the document images by combining a structural mechanics concept of DTD filter with Otsu binarization technique by effectively denoising the show-through noise. The proposed method was tested on various dataset images like DIBCO and Nabuco dataset. The results obtained from the comparative study of proposed DTD-cum-Otsu method with other six methods revealed that the proposed method removed the show-through noise very well and retaining the useful details irrespective of the degree of noise present. This is confirmed through visual inspection and estimated quality metrics. Further, the execution speed of the proposed method is well within the purview of the real-time implementation requirements. Consequently, the proposed DTD-cum-Otsu method can be deployed as a potential method for removing the show-through noise inherited in scanned document images. Eventually, there is enough scope for improving the performance of the algorithm by applying parallel processing, FPGA, GPU and other latest techniques, which will be taken up as a future scope of this study.

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