cse@buffalo

PDE-based Enhancement of Low Quality Documents

Ifeoma Nwogu

inwogu@cse.buffalo.edu

Outline

- Problem Statement
- Proposed Approach
- Results
- Future Work

Problem statement

- Enhancement is required when there is low variation between the foreground and background. Causes include:
  - similarities in intensity values,
  - low contrast,
  - similar texture patterns

Figure: Degraded synthetic text image

Proposed approach

- Exploits the regional smoothing of a **nonlinear diffusion process** to enhance the text in a degraded document.
- Can use **level-set methods** to fit models to the degraded images, thereby segmenting the foreground from the background.

Proposed approach cont'd

- We need to discretize the diffusion equation,

$$\frac{\partial u}{\partial t} = \mathbf{div}(g(|\nabla u|))\nabla u);$$

- Central differences is often the discretization of choice, where

$$|\nabla u_{i,j}| = \sqrt{\left(\frac{u_{i+1,j} - u_{i-1,j}}{2}\right)^2 + \left(\frac{u_{i,j+1} - u_{i,j-1}}{2}\right)^2}$$

- But central differences averages the diffusivities computed along three pixels, introducing smoothing around edges.

Proposed approach cont'd

- We replace the three-point difference by pixel midpoint differences.

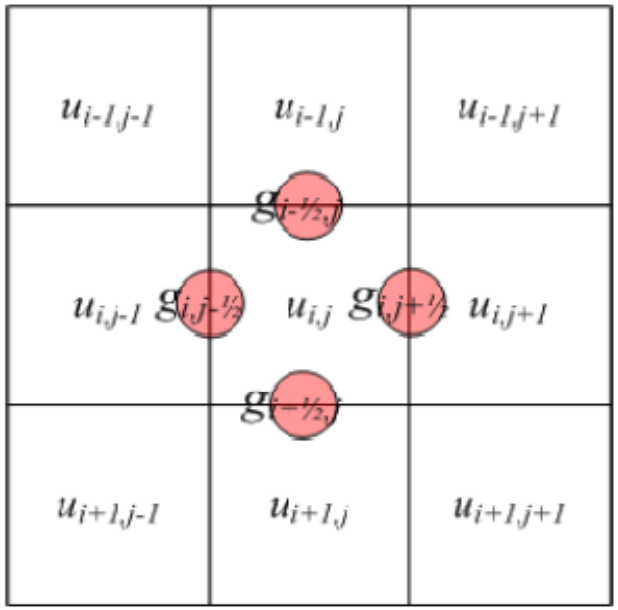


Figure: A 2-D grid showing diffusivities between the pixels involved in the diffusion process

Two-pixel mid-point differences

$$|\nabla u_{i+\frac{1}{2},j}| = \sqrt{(u_{i+1,j} - u_{i,j})^2 + \left(\frac{1}{2}\left(\frac{u_{i+1,j+1} - u_{i+1,j-1}}{2} + \frac{u_{i,j+1} - u_{i,j-1}}{2}\right)\right)^2}$$

$$|\nabla u_{i-\frac{1}{2},j}| = \sqrt{(u_{i,j} - u_{i-1,j})^2 + \left(\frac{1}{2}\left(\frac{u_{i-1,j+1} - u_{i-1,j-1}}{2} + \frac{u_{i,j+1} - u_{i,j-1}}{2}\right)\right)^2}$$

$$|\nabla u_{i,j+\frac{1}{2}}| = \sqrt{(u_{i,j+1} - u_{i,j})^2 + \left(\frac{1}{2}\left(\frac{u_{i+1,j+1} - u_{i-1,j+1}}{2} + \frac{u_{i+1,j} - u_{i-1,j}}{2}\right)\right)^2}$$

$$|\nabla u_{i,j-\frac{1}{2}}| = \sqrt{(u_{i,j} - u_{i,j-1})^2 + \left(\frac{1}{2}\left(\frac{u_{i+1,j-1} - u_{i-1,j-1}}{2} + \frac{u_{i+1,j} - u_{i-1,j}}{2}\right)\right)^2}$$

Proposed approach cont'd

In order to solve our continuous equation we need to introduce an artificial variable required for time discretization, τ

becomes

$$\frac{\partial u}{\partial t} = \mathbf{div}(g(|\nabla u|))\nabla u),$$

$$\begin{aligned} u^{k+1} = u^k + \tau \quad & (g_{i+\frac{1}{2}j} \cdot (u_{i+1,j} - u_{i,j}) \\ & -g_{i-\frac{1}{2}j} \cdot (u_{i,j} - u_{i-1,j}) \\ & +g_{i,j+\frac{1}{2}} \cdot (u_{i,j+1} - u_{i,j}) \\ & -g_{i,j-\frac{1}{2}} \cdot (u_{i,j} - u_{i,j-1})) \end{aligned}$$

Results

Below is an example of the accuracy improvement of using the two-pixel mid-point differences over central differences.

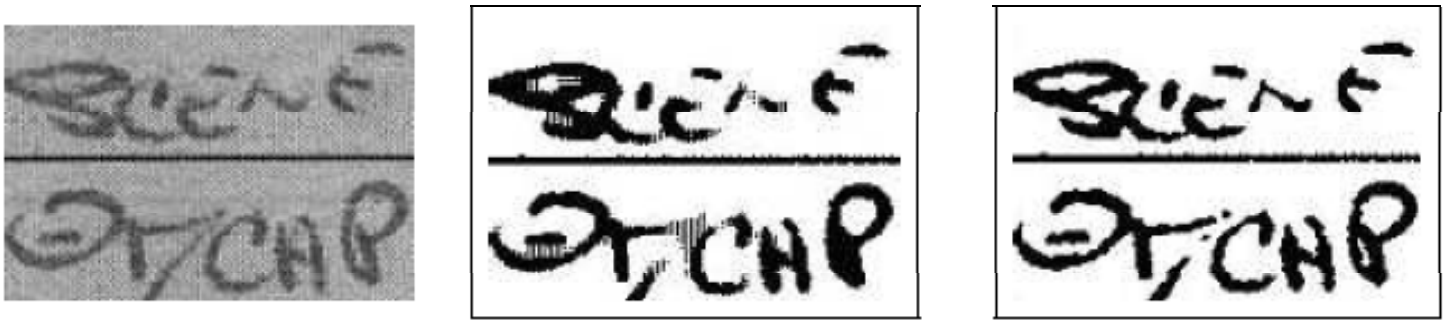


Figure: The left image is from the carbon copy of a PCR (patient care report) form. The middle image is enhanced using central differences; observe the burring at sharp corners. The right image is enhanced using the two-pixel mid-point differences.

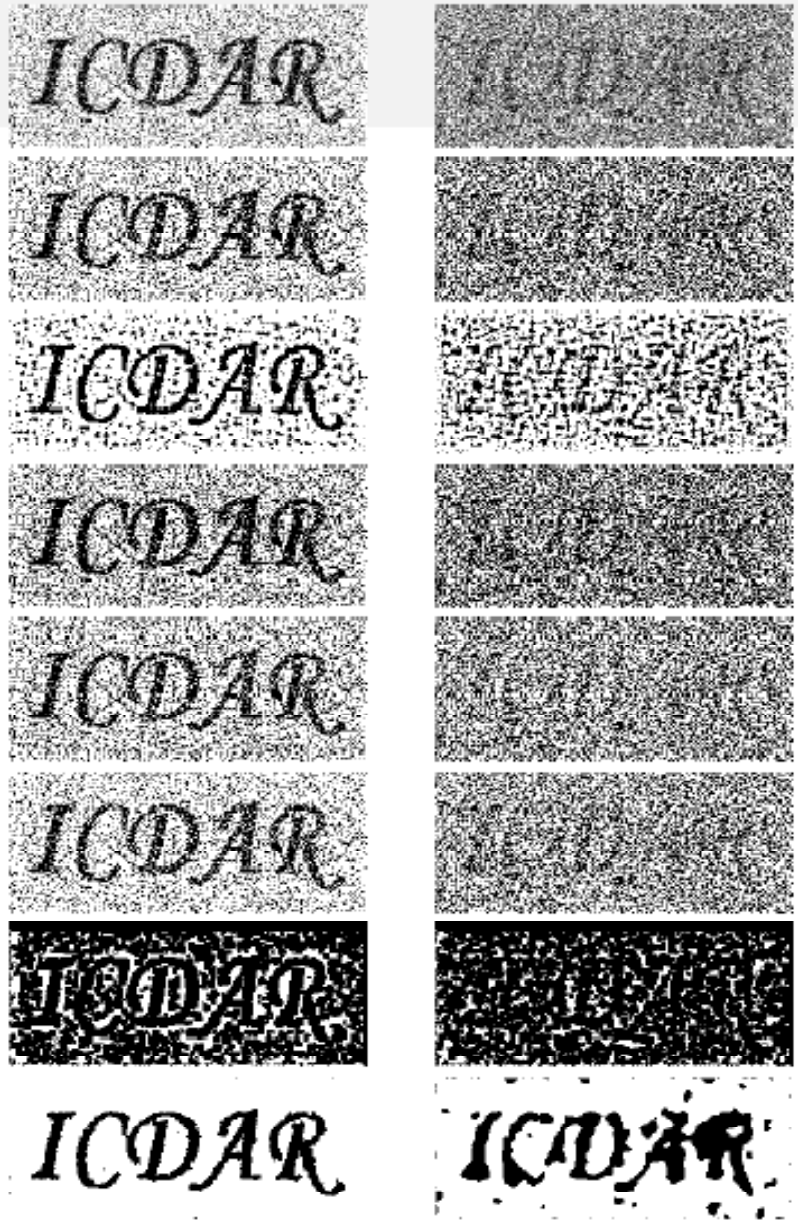
Results (quantitative evaluation)

Evaluation technique:

- create control image (with no noise),
- create test images with varying noise levels,
- apply different enhancement routines and binarize results
- measure the dissimilarity between the results and the control image.

Dissimilarity between 2 binary vectors *X* and *Y* is given as:

$$D(X,Y) = \frac{1}{2} - \frac{S_{11}S_{00} - S_{10}S_{01}}{2\sqrt{(S_{10}+S_{11})(S_{01}+S_{00})(S_{11}+S_{01})(S_{00}+S_{10})}}$$


(a)
Original with 50% and 90% SNR
(b)
Otsu's algorithm
(c)
Electronic Character Reading System
(d)
Output of an averaging filter
(e)
Niblack's adaptive algorithm
(f)
Texture based algorithm by Liu and Srihari
(g)
Yasuda, Dubois and Huang
(h)
PDE-based algorithm

Evaluation results

Enhancement technique	Dissimilarity (50% noise)	Dissimilarity (90% noise)
Otsu	0.2664	0.4392
Ethresh	0.1878	0.3692
Averaging filter	0.2749	0.4399
Niblack	0.2823	0.4479
Liu+Srihari	0.2581	0.4377
YDH algorithm	0.3773	0.4308
PDE-based algorithm	0.0346	0.1587

Table: Dissimilarity measures between the original noise-less image and the outputs of different techniques

Results (qualitative evaluation)

Visually examining the output of the algorithm:

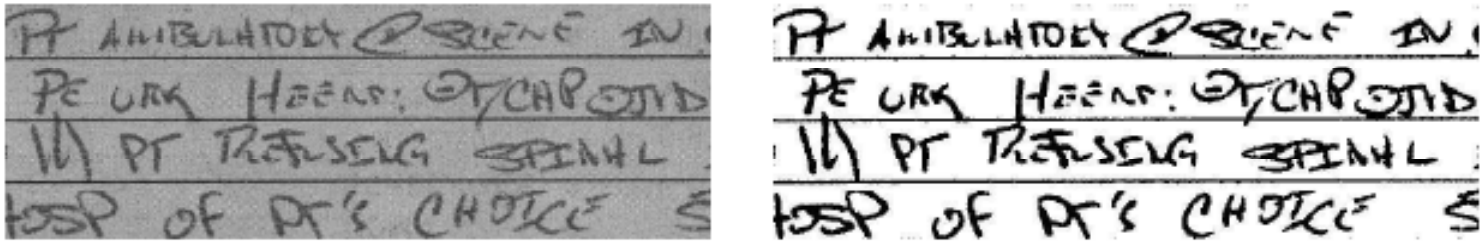


Figure: Enhancement of a portion of a low resolution carbon copy of the PCR form

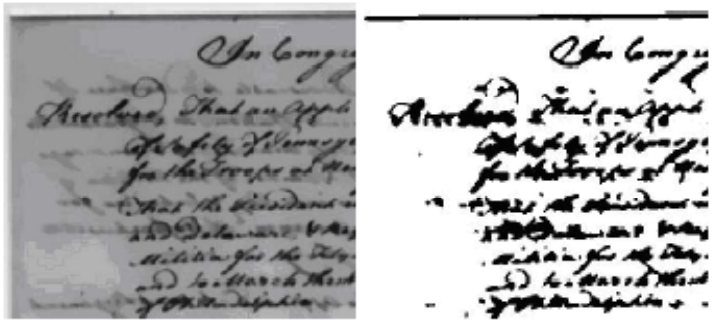


Figure: Enhancement of a portion of a low resolution historical document

Future work

- To use **level-set methods** to apply models to the degraded images, thereby segmenting multi-class problems.
- Fitting statistical models to the background, foreground and bleed-through text