Image Inpainting Using Field of Experts Model

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Abstract—Image Inpainting is a technique which recovers the deteriorated parts of a digital image. The process is carried out by filling the information from the area surrounding the damaged part of an image. The application areas of Image Inpainting includes scratch removal, image compression, image denoising, object and stamped date removal from photographs and creating visually stunning effect. In ancient era, this art was carried out manually by the artists, but now this process has been digitized to speed up the task and improve the accuracy of work done. This paper uses Field of Experts model to carry out image inpainting process and achieve the desired results. This model can also be used for image denoising application.

Keywords—Clique, Field of Expert, Higher Order Markov Random Fields, Image Inpainting, Product of Expert.

I. INTRODUCTION

Image Inpainting process aims to create reconstruction in damaged parts of an image such that it remains undetectable by a casual observer. The area surrounding damaged portions contain the useful information, which can be used to fill in the missing parts of an image. Image Inpainting method has wide variety of applications and is a major work carried out in the field of Image processing. Nowadays, photographers can use this technique to recreate deteriorated old images by removing scratches, red-eye, stamped date and objects from the digital photos.

Original Image

Inpainted Image

Fig-1 Image Inpainting

A number of techniques have been proposed to carry out Image Inpainting process. The basic approaches include diffusion based Image Inpainting and exemplar-based Image Inpainting. Diffusion based Image Inpainting uses algorithms that are based on variational methods and Partial Differential Equations (PDE) methods [1]. These methods are used to fill small and non-textured areas efficiently. The disadvantage of diffusion based method is that a blurring effect is noticeable while filling large textured areas. Exemplar based method works efficiently in comparison to diffusion based methods. The filling in the exemplar based methods is carried out by searching for the best matching patch from the source region. Once this patch is found the information is filled in the target region. This process is carried out iteratively till the whole target region is filled. The exemplar based methods can fill large and textured area effectively and can also preserve linear structures in the image [2].

II. FIELD OF EXPERTS MODEL

The Fields of Experts model is a statistical method developed to model the prior probability of an image. It is based on high-order Markov Random Fields and its potential function is represented as a Product of Experts [3], [4]. The inputs to the model are:

(i) Image to restore and
(ii) FOE parameters, which are learnt previously on a training dataset composed of images.

Fig-2: Field Of Experts Workflow (Courtesy of Stefan Roth from Brown University).

The Fields of Experts model has proven its efficiency in application to low vision problems [4]. However, there are some questions about its implementation. The parameters which are used have been learnt using a machine learning process on a generic dataset, the Berkeley Segmentation Benchmark [6].
These parameters are constants which are used in this implementation of inpainting processes, and are never reconsidered or recomputed [4]. They are independent of the image to be inpainted. This study tests the accuracy of these parameters.

A. Use of Field of Experts Model:

Field of Experts can be used as part of a Bayesian formulation. It can formulate likelihood (conditional on data) of original image and inpainted Image.

\[ p(x | y) \propto p(y | x) p(x) \]  

(1)

Where,

\( p(y | x) \): can be obtained from likelihood.

\( p(x) \): This term can be obtained from FOE model

The Fields of Experts (FoE) system aims to be more generic on low-vision issues. The main idea is to use whole images and not image patches to train the set of parameters. To do that, high-order Markov Random Fields are used with 'experts' to model linear filter responses that correspond to the expression of the Product of Experts (PoE) probabilistic model [3]. To take into account the whole image, we associate for each pixel \( k \in [1,K] \), a maximal clique \( x^{(k)} \). Assuming we have \( N \) 'experts', the potential function is:

\[ V_{\text{FoE}}(x_k) = \prod_{i=1}^{N} \phi(J^T_i x_k, \alpha_i) \]  

(2)

Where, each linear filter \( J_i \) sets the expert's orientation and will be learnt as well as the scalars \( \alpha_i \) on a set of images. The FoE model is finally defined by [4]:

\[ p_{\text{FoE}}(x, \Theta) = \frac{1}{Z(\Theta)} \prod_{k=1}^{K} \prod_{i=1}^{N} \phi(J^T_i x_k, \alpha_i) \]  

(3)

\[ \Leftrightarrow p_{\text{FoE}}(x, \Theta) = \frac{1}{Z(\Theta)} \exp\left\{ \sum_{k=1}^{K} \sum_{i=1}^{N} \Psi(J^T_i x_k, \alpha_i) \right\} \]  

(4)

Where \( \Psi = \ln \phi \)

The expert function chosen is based on the one introduced in [4] to preserve edges:

\[ \forall \alpha \in \mathbb{R}^*, \phi_{\alpha}(t, \alpha) = e^{-\alpha \sqrt{1+t^2}} \]  

(5)

Another choice could be to use the Student-t expert function defined previously or another non-parametric function as well.

B. Training:

To train the model, a dataset of \( D \) training images has been specified. It has to be pointed out that this training set \( x = \{x_1, \ldots, x_D\} \) represents different images from Berkeley Segmentation Benchmark [6] and not different patches of a same image. The training is made by minimizing the Kullback-Leibler divergence between the model and the data distribution, as it is shown below According to [4] it is equivalent to maximizing the likelihood of the probabilistic distribution. Denoting

\[ E(x, \Theta) = -\sum_{k=1}^{K} \sum_{i=1}^{N} \Psi(J^T_i x_k, \alpha_i) \]  

(6)

\[ \partial \Theta = v \left[ \langle \frac{\partial E}{\partial \Theta} \rangle - \langle \frac{\partial E}{\partial \Theta} \rangle x \right] \]  

where \( \langle \cdot \rangle_p \) is the average with respect to the distribution \( p \), \( \langle \cdot \rangle_x \) the average over the dataset image \( x \) and \( v \) is the learning rate. Practically, this is achieved using the contrastive divergence and produces a good approximation of the maximum likelihood.

III. Working Of Field Of Experts Model For Image Inpainting Process

Application of FoE model could take place in many low-vision problems, from stereo to object detection. It has been applied in this paper to image inpainting. Some optimizations have been made to make the algorithm faster. Although the model is expressed by its probabilistic distribution, an exact solution would be practically impossible to obtain. It is due to the high dimensionality of the problem (a lot of pixels), different intensity values for each variable (pixel), etc. So, an estimation of the solution is made by iterations of an algorithm which maximizes its posterior probability using techniques based on gradient optimization.

Denoting \( J^{(i)} \) the convolution filter corresponding to its associated filter \( J_i \), \( J^{(i)} \) obtained by mirroring \( J^{(i)} \) around its center, and \( \Psi' \) the derivative of \( \Psi \), this leads to:

\[ \nabla_x \ln p_{\text{FoE}}(x, \Theta) = \sum_{i=1}^{N} J^{(i)} \ast \Psi'(J^{(i)} \ast x, \alpha_i) \]  

(8)
To perform image inpainting, the user supplies a mask $M$, of pixels that are to be filled in by the algorithm. To define the appropriate likelihood, we assume that the masked pixels can take on any gray value with equal probability, and simply make the likelihood uniform there. Pixels that are not masked should not be modified at all. We can model this using Dirac delta centered on the pixel value to be preserved. We thus write the likelihood for image inpainting as follows:

$$L(y|x) = \prod_{k=1}^{p} \rho(y_k|x_k) \propto \prod_{k=1}^{p} \delta(y_k - x_k), k \in M \quad (9)$$

The algorithm modifies pixels 'marked' by the mask of pixels provided by the user which is denoted in the equation 10 by a matrix $M$ with the following iterative algorithm:

$$x^{(i+1)} = x^{(i)} + \eta M \left[ \sum_{i=1}^{N} J^{(i)} \ast \Psi' \left( J^{(i)} \ast x^{(i)} \right) \right] \quad (10)$$

IV. IMPLEMENTATION DETAILS

The algorithm for inpainting using Field of Experts model is given as follows:

1. Convert the given image to YCbCr, if the input image is RGB.
2. Perform sufficient number of iterations for fast convergence.
3. Initialize the gradient matrix to zero.
4. Evaluate log gradient.
5. Create filter mask and mirrored filter mask using the parameters obtained from model.
6. Convolve the image with filter mask and compute expert gradient.
7. Modify the gradient for only mask image.
8. Convert the image back to RGB.

The actual FoE model builds the filters from a training dataset composed of images. Basically, a learning process computes and tries to capture the spatial dependencies of neighboring cliques from different images, and to "encrypt" or to "code" them into a set of filters.

The FoE model has been implemented in Matlab 7.0 and embeds a standard set of filters. Those filters have practically been implemented on a very wide range of images, from animals to landscapes to humans [5].

This implementation contains two types of filters (three-by-three and five-by-five), they have been learnt on a training dataset composed of fifteen-by-fifteen image patches extracted randomly from the Berkeley Segmentation Benchmark [5],[6]. The result of this training (i.e. the visualization of the standard filters used in the implementation) can be shown as follows:

![Visualization of the set of eight 3 X 3 filters used by the standard implementation of the Fields of Experts model. (Courtesy of Stefan Roth from Brown University).](image1)

V. EXPERIMENTAL RESULTS

The implementation results of applying Field of Expert model for image inpainting carried out using Matlab 7 are provided as follows:

i. The input image is a black and white old image having scratch. The inpainting process reconstructs the missing information in the scratch portion and the result obtained is depicted in the figure below.

![Fig-4: Reconstruction of b/w old image having scratch.](image2)

ii. The input image is a RGB image having scratch. The inpainting process is carried out efficiently and results obtained are satisfactory. The figure below shows the output of reconstruction of a RGB image.
Fig-5: Reconstruction of a RGB image having scratch.

The input image is a textured image having wooden texture. There is a damaged portion (black colored shown in figure) in the textured area, which is reconstructed in the inpainted image. The result is shown in below figure.

Fig-6: Reconstruction of a textured image having damaged portion (black colored on top of image).

VI. CONCLUSION AND FUTURE WORK

The Field of Expert is based on a rich set of filters that are learned from data and is trained on generic image database using contrastive divergence technique. This model can be used in any Bayesian inference method, which requires a prior spatial image. In this paper, the implementation of FoE model is carried out for the application of Image Inpainting and results obtained are satisfactory. Still better learning algorithms are needed to capture natural image statistics. The filters size 5x5 is small to capture the statistics at coarse resolution. FoE model uses relatively simple parametric functions, but non parametric experts also need to be considered for further improvement of framework.

The clique size and shape needs to be selected automatically instead of choosing it from prior. An improved result can be made possible by making the model more powerful. Moreover, its application can be extended to non-image based graphs such as surface meshes or MRF models of object parts.

REFERENCES