Denoising And Inpainting Techniques forRestoration of Images

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Abstract— Digitalinpaintingisthetechniqueoffillinginthemissingregionsofanimageusinginformationfromthesurroundingareainavisuallyindistinguishableway.Inthispaper,wetrytoimprovetheExemplarbasedmethod[2]bymanipulating the values of various parameters like patch size,shape and size of the mask. We present an analysis of the impactofvariousgeometricparametersonthequalityofinpaintedimages.Imagedenoisingrefers totheremovalofunwantednoisefromtheimages.Inmostcases,theimageswhichneedto be inpainted are noisy, which makes it necessary to eliminatenoiseandfillinthemissingregionsfromneighboringpixels.Therefore,fillinginofmissingregionsandremovalofnoisearethetwoveryimportanttopicsinimageprocessing.Thispaperalsoaddressestheissueofperformingbothinpaintinganddenoisingsimultaneouslyusingtwodifferentapproaches:pipelinedapproachandinterleavedapproach.Theeffectivenessof these approaches is demonstrated with a number of results onvariousimages.

Index Terms—Image inpainting, Denoising, Restoration, Ex-emplar,Userinteraction,Imagecompletion.

1. INTRODUCTION

The concept of image inpainting was first introduced byBertalmioetal.[1].ThemethodwasbasedontheuseofPDEsand diffusion process. Bertalmio et al. [6] introduced anothermethod using the framework of the Navier-Stokes equations.Masnou and Morel [7] proposed an inpainting algorithm basedonlevellines.ChanandShendescribedimageinpaintingalgorithms[8]basedontheTVmodel. Oliveira[9]inpaintsbyrepeatedlyconvolvingafiltermaskwiththeinpaintingdomain.Wangetal.[10]describedaninpaintingtechniquethatisbasedon the propagation of isophotes. Later, Bertozzi et al. [11]proposed an inpainting technique based on the Cahn-Hilliardequation.

Exemplar based approach proposed by Criminisi et al. [2]fills in large regions by combining the use of both texturesynthesisandisophotedriveninpainting.Thisapproachisbasedonfirstpropagatingimagestructure(regionsboundaries)in the target region and then propagating texture informationfrom surrounding areas constrained by this structure. Structurereconstruction is performed in order to preserve the globalstructure of the image, by creating regions in the hole withwelldefinedboundariessuchthattheymatchthesurroundings.It also gives higher priority of synthesis to those regions oftarget area which lie on the continuation of image structures.Whilethetexturesynthesisstageisimportant,thestructurecompletionaspectisavitalcomponentinimprovingtheperceptual image inpainting quality. There are a number ofapproaches which are based on the Exemplar based inpaintingalgorithm.Someofthesetechniquesposesomeconstraintson the Exemplar based algorithm while others have modifiedfew steps of the algorithm. Here, we describe some of thetechniquesbasedonExemplarapproach.

WuandRuan[12]introducedacrossisophotesdataterminexemplarbasedinpainting.Nieetal.[13] proposedanimprovedsimilaritybasedimageinpaintingmethod.Kuoetal.[14]describedanadaptive restoredapproachbasedongradient-basedanalysisinspiredbytheadvantagesofthecolorinterpolationandtheexemplar-basedinpaintingmethods.Wong and Orchard [15] described the use of nonlocal imageinformationfrommultiplesampleswithintheimage.Hunget al. [16] proposed a novel algorithm based on mean shiftsegmentation and Bezier curves. Qin and Wang [17] tried toaddresstheshortcomingsofExemplarbasedapproach.XuandSun[18]introducedtwonovelconceptsofsparsityatthepatchlevel for modeling the patch priority and patch representation,whicharetwocrucialstepsforpatchpropagationintheexemplar-basedinpaintingapproach.

In this paper, we have addressed the drawback of Exemplarbasedapproachbymanipulatingsomeofthegeometricparam-eters which play a vital role in the process of inpainting. Wehave analyzed the effect of manipulating the values of variousgeometric parameters like patch size, mask size, mask shape,typeoftheimageonthefinaloutcomeofinpainting.

Also, most of the images comprising of some lost or dete-riorated regions which require fill-in, generally are corruptedwith noise. Hence, image inpainting and denoising are quiterelatedtopicsinthefieldofimageprocessing.Thispaperpresents approaches for simultaneously performing inpaintingand denoising on given noisy degraded images. Inpainting ofthe images has been performed by following the approach ofExemplar based method [2] and Fields of Experts model [3],[4]. Denoising of images has been performed based on theFields of Experts model [3], [4]. User interaction is extremelyimportant for our system which takes all the above parametersas input and performs inpainting and denoising operation onthe image. In the next section, we describe the purpose of userinterventionintheprocessofinpaintinganddenoising.

Inthispaper,wehaveincludedtheimages/figuresfromtheoriginalsourcesrequiredfortheexplanationofthebackgroundworkandhavecitedthereferenceswhereverrequired.

I. PURPOSEOFUSERINTERVENTION

Since some of geometric parameters like patch size, masksizeandshapeandthegivenimagetypeplayavitalrolein the image inpainting process (as would be discussed indetailinthenextsection)andparametertweakingyieldsbetterresultsthanusingthedefaultparametersasmentionedinthe Exemplarapproach, hence,their values mustbe alteredbytheusertoobtainnearlyaccurateinpaintedresults.Inthispaper,wehavedealtwiththisissue ofanalyzingtheimpactofparametermanipulationontheExemplarbasedinpainting approach. We have compared the results obtainedbysettingvariouspatchsizesandweobservedthatataparticular value of patch size or for a particular range of patchsizes, the results obtained were satisfactory and very poor,otherwise. Hence, user interaction is extremely important forour system to generate praiseworthy results. Also, we havesimultaneously performed inpainting and denoising on a givennoisy degraded image. This also requires considerable amountofuserinteractionsinceforinpainting,hehastospecifytheabovementionedparametersandthen,bothinpaintingand denoising can be performed in an interleaved manner.Also, user has the freedom to perform inpainting first followedby denoising or vice-versa or both inpainting and denoisingsimultaneously. Now, this parallel approach requires that thevalues of above mentioned parameters need to be specified,also, the number of iterations of inpainting, denoising and thetotal number of iterations should be mentioned by the user.The number of these iterations depends on the given image,level of noise present in the image, inpainting region to befilled-in. In such parametric centric system, user interventionplaysasignificantrole.

II. EFFECTOFPARAMETERSONINPAINTING

Some of the geometric parameters play a vital role in theprocess of inpainting. Parameter tweaking results in fairly bet-ter quality inpainting than obtained by applying the Exemplarbasedapproach.

Factors which have a great impact on the quality of theinpaintedimagesare:(i)PatchSizewhichreferstothesizeof the patch selected for filling in the target region, (ii) Shapeand Size of the mask which means the number of the pixelscoveredbythetargetregionwhichneedstobefilledinusing the inpainting algorithm, shape of the mask implies thepolygonalboundaryofthetargetregionselectedbytheuser,
(iii) Type of the given image which refers to the kind of imageto be inpainted, comprising of natural scenes or geometricshapes.

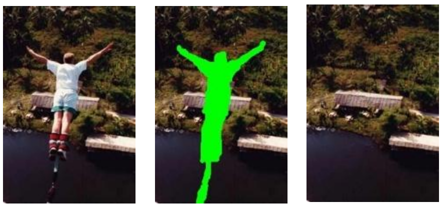
The above 3 factors are not independent of each other. Onefactor influences the others. Now, we describe the impact ofthesevariousparametersonthequalityoftheinpaintedresult.

A. *Typeoftheimage*

Images can be broadly classified into two types: (i) imagescomprising of natural scenes which have a high smoothnessfactor,and(ii)imagesofgeometricobjectscomprisingofvariousgeometricshapes,geo metricobjects.Theedgesoftheseobjectsarelinear(straightlines).

B. *Patchsize*

Forimagesofnaturalscenes,generallyasmallerpatchsize is selected so that it can closely approximate the curvedstructures. In case, if a larger patch size is selected, then thestaircaseartifactwillbemorepronouncedandforimagesof geometric objects, patch size selected should be generallylarger because the geometric objects are composed of linearstructures(straightlinesegments).

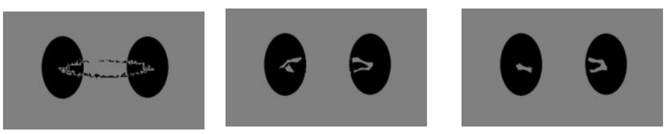


(a) (b) (c)

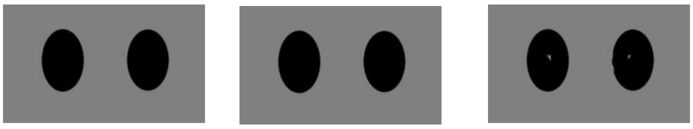
Fig.1:Resultofimageinpainitngofanimagecomprisingof geometric shapes requires a smaller patch size of 9 by 9pixels.

Moreover, in addition to the above facts, appropriate selec-tion of patch size is further dependent on the size of the targetregion or mask size (or in other words, the ratio of the sourceregiontothetargetregion).

Following results have been obtained by manipulating thevalues of the parameters in the Exemplar based approach. InFigure 2 and Figure 4, various results are obtained by varyingthepatchsize.



(a)3×3patch (b)9×9patch (c)17×17patch

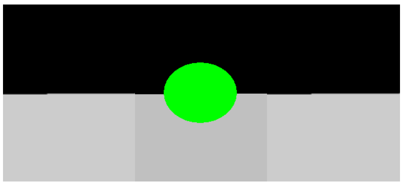


(d)41×41patch (e)67×67patch (f)75×75patch

Fig.2:Resultsofinpaintinganimagecomprisingofgeometricshapeswithdifferentpatchsizes.

C. Shapeandsizeofthemask

Given an image, filling a smaller mask would yield moreappropriateresultthanfillingalargermask.Thisisbecauseforagivenimage,asmallermaskensuresalargersourceregion

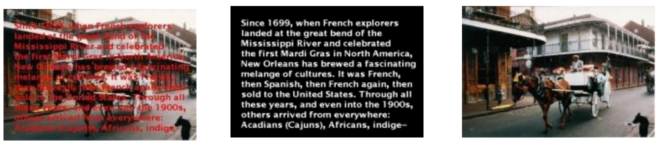


(a) (b) (c)

Fig.3:Resultofimageinpaintingwithpatchsizeof47by47.

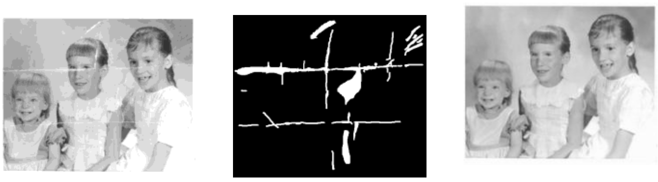
(a) 3×3patch (b)5×5patch (c)9×9patch(d)13×13patch

Fig. 4: Result of inpainting an image comprising of naturalscenewithdifferentpatchsizes.



(a) (b) (c)

Fig.5:Resultoftextremovalwithpatchsizeof9by9.



(a) (b) (c)

Fig.6:Resultofimagerestorationwithpatchsizeof9by9.

which implies more information is available to fill in the targetregion, the best matching patch can be found out from a widevariety of patches present in the source region, hence, yieldingmore accurate result. In contrast, a larger mask would meancomparatively smaller source region i.e. the information usedtofillinthetargetregionisnotadequate.

Shape of the mask determines the kind of polygonal bound-ary selected by the user which encloses the target region to befilledinbythealgorithm.Thisfactorwillultimatelydeterminethesizeofthetargetregion.

Also, in inpainting, few more characteristics of the imagecome into picture i.e. the intensity, and texture. If the imagehas uniform background or foreground with respect to thecolor of all its pixels or it has homogeneous texture, then evenfilling a larger target region would yield a fairly good qualityresult. But, in contrast, if the image has heterogeneous textureandvariedintensities,thenselectingasmallermaskwouldbebeneficial as the surrounding pixels will play a major role infiling the area and thus the concepts like locality of referenceand the proximity to the specified target region would comeintopicture.

III. SIMULTANEOUS INPAINTING AND DENOISING

Inthissection,weaddressthisissueofsimultaneousdenoisingandinpainting.

A. *InpaintingfollowedbyDenoising*

In this approach, the target region is filled in first and thenthenoiseiseliminatedfromtheimage.

B. *DenoisingfollowedbyInpainting*

In this approach, denoising and inpainting are carried out ina pipelined manner one after the other. First, noise removal iscarried out followed by the fill-in of the missing region. Themajor disadvantage of following this approach is that carryingout denoising first blurs the image. Because of the applicationofseveralfilterstoremovenoise,blurringisintroducedintheimage.But,themaskhasbeen constructedwithrespectto the original image. Mask has not been modified by theapplication of filters, so, it has not undergone any blurring.Hence, inpainting of the blurred image would be performedwiththesameoriginalimagebasedmask.Therefore,theoutputobtainedisnotofsupremequality.

C. *InpaintingandDenoisinginInterleavedmanner*

Stepsfollowedinthistechniqueare:

1) Inpaint the image inside the inpainting region. M itera-tionsofinpaintingareperformed.
2) SmoothingprocessstartsafterthecompletionofMstepsof inpainting. N iterations of denoising are performedusingtheFieldsofExpertsmodel.
3) Repeattheabove1)and2)stepsKtimes.

Followingarethe advantagesanddisadvantagesofadoptingthisinterleavedapproach:

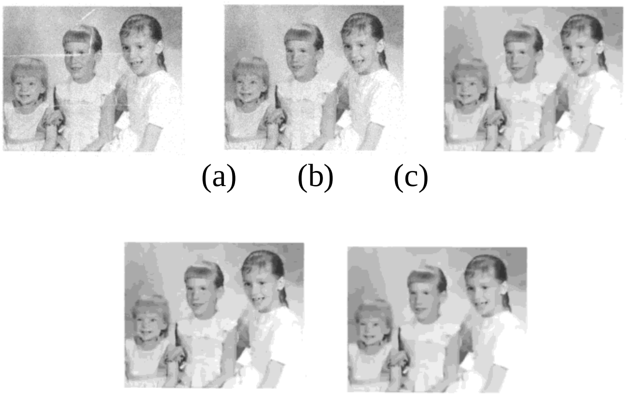
1) *Advantages:* If the values of M and N are small and thevalue of K is quite large, then the results obtained are of goodquality. Values of M, N and K are dependent on the givenimage, the given mask size, the level of noise with which theimageiscorrupted.
2) *Disadvantages:*By increasing the value of K and de-creasing the values of M and N, the overhead and the runningcostincreasestremendously.

2. RESULTS

Inthissection,resultsareobtainedbyperforminginpaintingfollowed by denoising, denoising followed by inpainting andinpainting and denoising in an interleaved manner. In Figure 7(b), (c), inpainting is performed using the Exemplar basedapproach using 9×9 patch followed by denoising using FieldsofExpertsmodel.Onthecontrary,inFigure7(d),(e),initiallythe image is denoised using Fields of Experts model and then,itisinpaintedusing13×13patchbyExemplarbasedapproach.InFigure8,interleavedmannerof performinginpaintinganddenoising is performed, where 10 iterations of inpainting arefollowed by 10 iterations of denoising and this loop repeatstwice.

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

Fig. 7: (a) Noisy image, (b) Inpainting the noisy image, (c)Denoising (b), (d) Denoising the noisy image, (e) Inpainting(d)



(a) (b) (c)

(d) (e)

Fig. 8: (a) Noisy image, (b) Inpainting step1 (10 steps inpaint-ing), (c) Denoising step1 (10 steps denoising) (d) Inpaintingstep2(10stepsinpainting)(e)Denoisingstep2(10stepsdenoising)

3. CONCLUSION

In this paper, we have analyzed the impact of various ge-ometric parameters on the inpainting process while followingthe Exemplar based approach. As evident from the results,parameter tweaking greatly improves the quality of the results.Alongwiththegiveninputimagewhichneedstobeinpainted,the user also has to specify the mask or the target region to befilled in, the patch size and the fill region color. Hence, userinteraction is extremely important for the system which takesall the above parameters as input and performs inpainting anddenoisingoperationontheimage.Also,wehaveproposedtwodifferentmethodologiesofperfor mingbothinpaintingand denoising simultaneously on a given degraded image: thepipelinedapproachwhereinpaintingisperformedfollowedby denoising and vice versa and the interleaved approach inwhich few iterations of inpainting are performed followed byfewiterationsofdenoising.Inthepipelinedapproach,weobservedfromtheresultsthatinpaintingf ollowedbydenoisingyields better results than performing denoising first followedby inpainting. But, the interleaved manner of performing bothinpaintinganddenoisingoutperformsthepipelinedapproach.

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