Image Restoration using Multiresolution Texture Synthesis and Image Inpainting

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Introduction : Motivation

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- Repairing damaged images
  - scratches on pictures or old films
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  - scratches on pictures or old films
- Fill in missing part of images
  - Images synthesized by IBR, etc.
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- Repairing damaged images
  - scratches on pictures or old films
- Fill in missing part of images
  - Images synthesized by IBR, etc.
- Delete unwanted objects on an image
  - subtitles, logos, microphones, ...
Intro: Repairing damages

Repairing damaged images

- scratches on pictures or old films

Photo from:
“Image Inpainting,”
M. Bertalmío, et al.,
SIGGRAPH 2000.

http://www.ece.umn.edu/users/marcelo/restoration.html
**Intro: Fill-in hole**

Fill in missing part of images

- Images synthesized by IBR, etc.

White triangles:

- occlusions
- registration errors
- etc..
Intro : Delete objects

Delete unwanted objects on an image

- subtitles, logos, microphones, ...

When defects are only thin lines. The restoration is easy.

This is such an example.
Damaged pixels

What are damaged pixels? / How to detect them?
Damaged pixels

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- Image sequences: Assuming temporal coherence
Damaged pixels

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- One image: Hard to say
Damaged pixels

What are damaged pixels? / How to detect them?

• Image sequences: Assuming temporal coherence

• One image: Hard to say
  • Unwanted object can not be detected automatically
Damaged pixels

What are damaged pixels? / How to detect them?

- Image sequences: Assuming temporal coherence
- One image: Hard to say
  - Unwanted object cannot be detected automatically
- Here, we should manually specify restoration area
Image Restoration

- **Solving PDE:**
  - diffuses intensity from boundary pixels
  - can keep smoothness of image
  - can not reconstruct details

- **Texture synthesis:**
  - searches similar patterns and arranges them
  - can reconstruct details
  - can not reconstruct smoothness of image

Question

Can we combine both advantages without including disadvantages?
Image Restoration

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PDE method

- Anisotropic diffusion
  - *M. Bertalmío, et al.*, “Image Inpainting”, *SIGGRAPH 2000*
- Isotropic diffusion
- Interpolating height field with bicubic B-spline surface

\[\downarrow\]

Assuming image height field continuity
PDE method : Example (1)

Input Image

When defects are only thin lines. The restoration is easy.

This is such an example.
PDE method: Example (1)

Mask Image

*When defects are only thin lines. The restoration is easy.*

*This is such an example.*
PDE method : Example (1)

Image with Mask

When defects are only thin lines, the restoration is easy.

This is such an example.
PDE method : Example (1)

Fast Digital Image Inpainting : Gaussian diffusion
PDE method : Example (1)

Image Inpainting : Anisotropic diffusion
PDE method : Example (2)

Input Image
PDE method : Example (2)

Image with Mask
PDE method : Example (2)

Fast Digital Image Inpainting : Gaussian diffusion
PDE method : Example (2)

Image Inpainting : Anisotropic diffusion
PDE method : Hard case

Input Image
PDE method: Hard case

Image with Mask
PDE method : Hard case

Fast Digital Image Inpainting : Gaussian diffusion
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Image Inpainting : Anisotropic diffusion
PDE method: Pros & Cons

PDE based methods

- Advantages:
  - Keeping boundary conditions
  - Keeping inside area's continuity
PDE method: Pros & Cons

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- Disadvantages:
  - Too much smoothing inside the masked area
  - High frequency component is hard to reconstruct

Anisotropic diffusion tries to reconstruct high frequency part, but it is limited.
PDE method : Pros & Cons

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    → Anisotropic diffusion tries to reconstruct high frequency part, but it is limited
Texture synthesis (1)

What is a texture?
Texture synthesis (1)

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What is a texture?

Texture: An image that exhibits spatial homogeneity
Texture synthesis (2)

Using spatial homogeneity for synthesis

Input
Texture synthesis (2)

Using spatial homogeneity for synthesis
Texture synthesis: Classification

- Procedure based
  - Fractal, Cellular textures (Fleischer 1995), Reaction diffusion (Turk 1991)
Texture synthesis: Classification

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  - Fractal, Cellular textures (Fleischer 1995), Reaction diffusion (Turk 1991)
- Statistics analysis and synthesis
  - Pyramid-Based Texture Analysis/Synthesis (Heeger 1995)
  - Texture Mixing and Texture Movie Synthesis Using Statistical Learning (Bar-Joseph 2001)
Texture synthesis: Classification

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  - Texture Mixing and Texture Movie Movie Synthesis Using Statistical Learning (Bar-Joseph 2001)
- Non-parametric Sampling
  - Texture Synthesis by Non-parametric Sampling (Efros 1999)
  - Fast Texture Synthesis Using Tree-Structured Vector Quantization (Wei 2000)
Non-parametric Sampling (1)

Initialize target image with random color pixels
Non-parametric Sampling (1)

Search similar kernel (red shape) on seed image
transfer a pixel
Non-parametric Sampling (1)

Search similar kernel (red shape) on seed image
transfer a pixel
Non-parametric Sampling (1)

Search similar kernel (red shape) on seed image
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Non-parametric Sampling (1)

Search similar kernel (red shape) on seed image transfer a pixel
Non-parametric Sampling (2)

- Advantage:

- Disadvantages:
  - Does not care about continuity/global structure
  - Not suitable for non-homogeneous textures
  - Many improvements
    - Multiresolution synthesis (Wei 2000, ...)
    - Coherent match method (Ashikhmin 2001)
    - Image Analogies (Hertzmann 2001)

...
Non-parametric Sampling (2)

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  - Can deal with high frequency components
Non-parametric Sampling (2)

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Our method

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- Low frequency part:
  Global structure/large gradient area
  ⇒ Solving PDE
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  ⇒ Non-parametric Sampling
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  Global structure/large gradient area
  \[\Rightarrow\text{Solving PDE}\]

- High frequency part:
  Texture/detail structure
  \[\Rightarrow\text{Non-parametric Sampling}\]

- To combine both methods:
  \[\Rightarrow\text{Frequency decomposition}\]
The Algorithm

Input Image

- Red part will be reconstructed
The Algorithm

Fill in hole region with diffusion

- Scratch and Text region is well reconstructed
- Large area: Problematic
The Algorithm

Frequency Decomposition

- Using FFT (DCT)
The Algorithm

Extract High Frequency Part

- (High frequency image is gamma corrected)
The Algorithm

Multiresolution Analysis
The Algorithm

Reconstruct by Non-Parametric Sampling (Level 2)
The Algorithm

Reconstruct by Non-Parametric Sampling (Level 1)
The Algorithm

Reconstruct by Non-Parametric Sampling (Level 0)
The Algorithm

High Frequency part is reconstructed

Some Text

⇒

+

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The Algorithm

Combine them together
Comparison

input texture

Some Text

Some Text
Comparison

input texture
non-parametric sampling (texture synthesis)
Comparison

- **input texture**
- **non-parametric sampling (texture synthesis)**
- **image inpainting**
Comparison

input texture

non-parametric sampling (texture synthesis)

image inpainting

our method

Some Text

Some Text
Decomposition parameter (1)

- **Question**
  - What frequency is the low/high frequency?
  - How can we choose the frequency decomposition parameter?
- Frequency decomposition parameter: $\kappa$
  - Upper bound for the low frequencies
Decomposition parameter (1)

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  - What frequency is the low/high frequency?
  - How can we choose the frequency decomposition parameter?
- Frequency decomposition parameter: $\kappa$
  Upper bound for the low frequencies

\[ \kappa = 2 \quad \kappa = 4 \quad \kappa = 8 \quad \kappa = 16 \]
Decomposition parameter (2)

- Hypothesis
  1. If the low frequency part is sufficiently removed, the rest part is more like a texture
  2. Spatial homogeneity can be measured by autocorrelation
Decomposition parameter (2)

- **Hypothesis**
  1. If the low frequency part is sufficiently removed, the rest part is more like a texture
  2. Spatial homogeneity can be measured by autocorrelation

- **Method**
  - Calculate the autocorrelation matrices of each $\kappa$
  - Compute the SD (standard deviation) of the matrices
  - Experimentally, we choose $\kappa$ at SD $\leq 0.001$
Correlation between $\kappa$ and SD

- Four example images (images will be shown up)
- SD is small when $\kappa$ is large
Results : Painting

HELLO WORLD

BYE
Results : Painting
Results : Posters
Results : Posters
Results : Wall
Results: Wall
Results : Tables
Results: Tables
Results : Excursion 1
Results : Excursion 1
Results: Excursion 1
Results: Cablecar
Results: Cablecar
Results : Excursion 2

image
Results : Excursion 2

input
Results : Excursion 2

image inpainting
Results: Excursion 2

multiresolution texture synthesis
Results : Excursion 2

our method
Conclusion

- Propose a new image restoration method
  → Frequency decomposition for combining image inpainting and texture synthesis
  → A criterion for deciding the decomposition parameter $\kappa$
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• Future Work
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  • Fuzzy mask
  • Image inpainting guided texture synthesis
    → using image inpainting to suggest the transfer region
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  • Fuzzy mask
  • Image inpainting guided texture synthesis
    → using image inpainting to suggest the transfer region
  • Expand to 3D
    • Image sequences
    • Fill in 3D holes
Acknowledgements

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    http://www.cns.nyu.edu/~david/
  - VisTex database
    http://www-white.media.mit.edu/vismod/imagery/VisionTexture/vistex.html
  - Cablecar photo by Goshima, Kazuhiro

Thank you and Questions?