Deblurring for spiral real-time MRI using convolutional neural networks

Yongwan Lim, Shrikanth S. Narayanan, Krishna S. Nayak

Ming Hsieh Department of Electrical and Computer Engineering, Viterbi School of Engineering, University of Southern California, Los Angeles, California, USA
Spiral Real-time MRI

Vocal Tract
Source: USC

Heart
Source: Max Plank BiomedNMR

Joints
Source: Chaudhari Lab, UC Davis
Spiral Real-time MRI

Vocal Tract
Source: USC

Heart
Source: Max Plank BiomedNMR

Joints
Source: Chaudhari Lab, UC Davis
Spiral Real-time MRI

Vocal Tract
- velum
- lips
- tongue

Heart

Joints

Source: Max Plank BiomedNMR
Source: USC
Source: Chaudhari Lab, UC Davis
Spiral Real-time MRI

Vocal Tract
- lips
- velum
- tongue

Source: USC

Heart

Source: Max Plank BiomedNMR

Joints

Source: Chaudhari Lab, UC Davis
Spiral Real-time MRI

Vocal tract

Spatially-varying blur due to spatial variations in the magnetic field

Source: USC
Spiral Real-time MRI

Vocal tract

Spatially-varying blur due to spatial variations in the magnetic field.

Source: USC
Spiral Real-time MRI

Spirally-varying blur due to spatial variations in the magnetic field

Vocal tract

Source: USC

Blurring Artifact

After De-Blurring
Off-resonance Deblurring

1. KS Nayak et al, MRM. 2001
2. BP Sutton et al, JMRI. 2010
3. Y Lim et al. MRM. 2019
4. DC Noll et al, MRM. 1992
Off-resonance Deblurring

1. Field map acquisition
   - Reduced scan efficiency

2. Spatially-varying deconvolution
   - Computationally slow (~minutes)

References:
1. KS Nayak et al, MRM. 2001
2. BP Sutton et al, JMRI. 2010
3. Y Lim et al. MRM. 2019
4. DC Noll et al, MRM. 1992
Off-resonance Deblurring

1. Field map acquisition
   • Reduced scan efficiency
2. Spatially-varying deconvolution
   • Computationally slow (~minutes)

1. KS Nayak et al, MRM. 2001
2. BP Sutton et al, JMRI. 2010
3. Y Lim et al. MRM. 2019
4. DC Noll et al, MRM. 1992
Off-resonance Deblurring

- Standard Approaches:\n  1. Field map acquisition
     - Reduced scan efficiency
  2. Spatially-varying deconvolution
     - Computationally slow (~minutes)

- Proposed Approach: A supervised end-to-end learning

---

1. KS Nayak et al, MRM. 2001
2. BP Sutton et al, JMRI. 2010
3. Y Lim et al. MRM. 2019
4. DC Noll et al, MRM. 1992
Off-resonance Deblurring

• Standard Approaches\(^1-^4\):
  
  1. Field map acquisition
     • Reduced scan efficiency
  2. Spatially-varying deconvolution
     • Computationally slow (~minutes)

• Proposed Approach: A supervised end-to-end learning

1. KS Nayak et al, MRM. 2001
2. BP Sutton et al, JMRI. 2010
3. Y Lim et al. MRM. 2019
4. DC Noll et al, MRM. 1992
Off-resonance Deblurring

• Standard Approaches\textsuperscript{1-4}:
  
  1. Field map acquisition
     • Reduced scan efficiency
  2. Spatially-varying deconvolution
     • Computationally slow (~minutes)

• Proposed Approach: A supervised end-to-end learning

1. KS Nayak et al, MRM. 2001
2. BP Sutton et al, JMRI. 2010
3. Y Lim et al. MRM. 2019
4. DC Noll et al, MRM. 1992
Off-resonance Deblurring

- **Standard Approaches**:
  1. Field map acquisition
     - Reduced scan efficiency
  2. Spatially-varying deconvolution
     - Computationally slow (~minutes)

- **Proposed Approach**: A supervised end-to-end learning

In test time
1. Does NOT rely on field map
2. FAST (~milliseconds)

References:
1. KS Nayak et al, MRM. 2001
2. BP Sutton et al, JMRI. 2010
3. Y Lim et al. MRM. 2019
4. DC Noll et al, MRM. 1992
Off-resonance Deblurring

• Standard Approaches\textsuperscript{1-4}:

1. Field map acquisition
   • Reduced scan efficiency
2. Spatially-varying deconvolution
   • Computationally slow (~minutes)

• Proposed Approach: A supervised end-to-end learning

In test time
1. Does NOT rely on field map
2. FAST (~milliseconds)

\textsuperscript{1} KS Nayak et al, MRM. 2001
\textsuperscript{2} BP Sutton et al, JMRI. 2010
\textsuperscript{3} Y Lim et al. MRM. 2019
\textsuperscript{4} DC Noll et al, MRM. 1992
Proposed Supervised Deblurring

1. Y Lim et al. MRM. 2019
2. Y Lim et al. MRM. 2020

- Simulate blurring based on MRI physics and data augmentation
- Train CNNs
- Deblur residual blurring using a previous method
Proposed Supervised Deblurring

1. Y Lim et al. MRM. 2019
2. Y Lim et al. MRM. 2020

- Deblur residual blurring using a previous method\(^1\)
- Simulate blurring based on MRI physics and data augmentation\(^2\)
- Train CNNs

Field Map | Ground Truth
---|---

1. Y Lim et al. MRM. 2019
2. Y Lim et al. MRM. 2020
Proposed Supervised Deblurring

1. Y Lim et al. MRM. 2019
2. Y Lim et al. MRM. 2020

- Simulate blurring based on MRI physics and data augmentation
- Train CNNs
- Deblur residual blurring using a previous method

- 23 subjects > 64K frames
- Parameters: $T_{\text{read}}, \alpha, \beta$
Proposed Supervised Deblurring

1. Y Lim et al. MRM. 2019
2. Y Lim et al. MRM. 2020

1. Deblurr residual blurring using a previous method
2. Simulate blurring based on MRI physics and data augmentation

23 subjects
> 64K frames
Parameters: $T_{\text{read}}, \alpha, \beta$

Ground Truth
Blurred Image

Convolutional Neural Networks

Train CNNs
Proposed Supervised Deblurring

1. Y Lim et al. MRM. 2019
2. Y Lim et al. MRM. 2020

Deblur residual blurring using a previous method\(^1\)

Simulate blurring based on MRI physics and data augmentation\(^2\)

Train CNNs

23 subjects > 64K frames

Parameters: \(T_{\text{read}}, \alpha, \beta\)

1. Y Lim et al. MRM. 2019
2. Y Lim et al. MRM. 2020
Result: Synthetic Test Data

**Image**

- **Ground truth**
- **Uncorrected**

|          | PSNR     | SSIM     | HFEN     |
|----------|----------|----------|----------|
|          | 22.16 ± 1.413 | 0.812 ± 0.039 | 0.568 ± 0.131 |

1. LC Man et al. MRM. 1997  
2. BP Sutton et al. MRM. 2003
Result: Synthetic Test Data

|   | Ground truth | Uncorrected | MFI$^1$ with ref. field map | IR$^2$ with ref. field map | Proposed |
|---|--------------|-------------|----------------------------|---------------------------|----------|
|   |              |             |                            |                           |          |
| Image |              |             |                            |                           |          |
| Lips |              |             |                            |                           |          |
| Soft palate |          |             |                            |                           |          |
| Tongue |              |             |                            |                           |          |

|   | PSNR | SSIM | HFEN |
|---|------|------|------|
|   | 22.16 ± 1.413 | 0.812 ± 0.039 | 0.568 ± 0.131 |
| Corrected | 20.75 ± 1.363 | 0.875 ± 0.023 | 0.448 ± 0.113 |
| Proposed | 38.53 ± 1.259 | 0.992 ± 0.002 | 0.004 ± 0.003 |
|   | 29.30 ± 1.762 | 0.944 ± 0.016 | 0.088 ± 0.049 |

1. LC Man et al. MRM. 1997  
2. BP Sutton et al. MRM. 2003
Result: Synthetic Test Data

| Image | Ground truth | Uncorrected | MFI\(^1\) with ref. field map | IR\(^2\) with ref. field map | Proposed |
|-------|--------------|-------------|-------------------------------|-----------------------------|----------|
| ![Images](image.png) |![Images](image.png) | ![Images](image.png) | ![Images](image.png) | ![Images](image.png) | ![Images](image.png) |

| Metric | Ground truth | Uncorrected | MFI\(^1\) | IR\(^2\) | Proposed |
|--------|--------------|-------------|-----------|---------|----------|
| PSNR   | 22.16 ± 1.413 | 20.75 ± 1.363 | 38.53 ± 1.259 | 29.30 ± 1.762 |
| SSIM   | 0.812 ± 0.039 | 0.875 ± 0.023 | 0.992 ± 0.002 | 0.944 ± 0.016 |
| HFEN   | 0.568 ± 0.131 | 0.448 ± 0.113 | 0.004 ± 0.003 | 0.088 ± 0.049 |

1. LC Man et al. MRM. 1997  
2. BP Sutton et al. MRM. 2003
Result: Synthetic Test Data

**Ground truth**

Uncorrected

MFI$^1$ with ref. field map

IR$^2$ with ref. field map

**Proposed**

Image

|       | PSNR       | SSIM       | HFEN       |
|-------|------------|------------|------------|
| Ground truth | 22.16 ± 1.413 | 0.812 ± 0.039 | 0.568 ± 0.131 |
| Uncorrected   | 20.75 ± 1.363  | 0.875 ± 0.023  | 0.448 ± 0.113  |
| MFI$^1$ | **38.53 ± 1.259** | **0.992 ± 0.002** | **0.004 ± 0.003** |
| IR$^2$ | 29.30 ± 1.762 | 0.944 ± 0.016 | 0.088 ± 0.049 |

1. LC Man et al. MRM. 1997  
2. BP Sutton et al. MRM. 2003
Result: Real Test Data

Uncorrected  IR with estimated field map\textsuperscript{1}  Proposed

Readout = 7.94 ms  Temporal resolution = 46 ms

1. Y Lim et al. MRM. 2019
Summary

• We develop a CNN-based deblurring method for spiral RT-MRI in speech production.

• It is field-map-free and effective at resolving spatially varying blur at the articulator boundaries.

• It is extremely fast (12.3 ms per-frame) with negligible impact on latency or workflow for RT-MRI applications.
Deblurring for spiral real-time MRI using convolutional neural networks

Yongwan Lim, Shrikanth S. Narayanan, Krishna S. Nayak

Ming Hsieh Department of Electrical and Computer Engineering, Viterbi School of Engineering, University of Southern California, Los Angeles, California, USA

Thank you for your attention!

If you have any questions, please contact me: yongwanl@usc.edu