[11] Super resolution is another conventional method for image resolution improvement: the original image m_{LR} is acquired with low resolution, and the reconstructed image m_{SR} is with better image resolution. m_{SR} can be obtained by increasing the matrix size of m_{LR} and estimating the additional high spatial frequency contents that have not been acquired. Since low resolution images require less acquisition time, the super resolution method can also shorten MR scan time.

[12] Similar to the previous formulations, the super resolution reconstruction can also be represented by a function *f* that transforms a low resolution image to a high resolution image $\widetilde{m}$.

$$\widetilde{m} = f(m_{\mathrm{LR}}),$$

[13] The major challenge for the super resolution method is that the un-acquired high spatial frequency information (or function *f*) is difficult to estimate directly. Thus, a need exists for an improved system for MR imaging.

SUMMARY

[14] The present disclosure provides improved Magnetic Resonance Imaging (MRI) systems that can address various drawbacks of conventional systems, including those recognized above. Method and system of the presenting disclosure provide improved image quality with shortened image acquisition time. The computation time for image reconstruction in runtime may also be reduced compared to the standard iterative reconstruction methods. The provided method and system may significantly reduce MR scan time by applying deep learning techniques for image reconstruction so as to enhance image quality. Examples low quality in medical imaging may include noise (e.g., low signal noise ratio), blur (e.g., motion artifact), shading (e.g., blockage or interference with sensing), missing information (e.g., missing pixels or voxels in painting due to removal of information or masking), reconstruction (e.g., degradation in the measurement domain), and/or under-sampling artifacts (e.g., under-sampling due to compressed sensing, aliasing). Methods and systems of the present disclosure can be applied to existing systems seamlessly without a need of a change of the underlying infrastructure. In particular, the provided methods and systems may improve MR image quality at no additional cost of hardware component and can be deployed regardless of the configuration or specification of the underlying infrastructure.

[15] In an aspect of the disclosure, a computer-implemented method is provided for improving image quality with shortened acquisition time. The method comprises:

determining an accelerated image acquisition scheme for imaging a subject using a medical imaging apparatus, wherein the accelerated image acquisition scheme comprises one or more parameters related to at least one of an undersampled k-space, an undersampling pattern, and a reduced number of repetitions, and wherein the accelerated image acquisition scheme is determined based on user input and real-time simulated output images; acquiring, using the medical imaging apparatus, a medical image of the subject according to the accelerated image acquisition scheme, wherein the medical image comprises a magnetic resonance image; applying a deep network model to the medical image to improve the quality of the medical image; and outputting an improved quality image of the subject for analysis by a physician. In some embodiments, the medical image includes a magnetic resonance image.

[16] In some examples of the disclosure, determining the accelerated image acquisition scheme comprises: receiving a target acceleration factor or target acquisition speed via a graphical user interface, and selecting from a plurality of accelerated image acquisition schemes based on the target acceleration factor or the target acquisition speed. In some cases, the accelerated image acquisition scheme is selected by applying the plurality of accelerated image acquisition schemes to a portion of the medical image for simulation.

[17] In some examples, the accelerated image acquisition scheme is determined based on user input and real-time simulated output images. In some examples, the accelerated image acquisition scheme comprises one or more parameters related to an undersampled k-space, an undersampling pattern, and a reduced number of repetitions. In some cases, the undersampling pattern is selected from a group consisting of a uniform undersampling pattern, a random undersampling pattern, and a variable undersampling pattern. In some examples, the medical image comprises undersampled k-space image or image acquired using reduced number of repetitions.

[18] In some examples, the deep learning model is trained with adaptively optimized metrics based on user input and real-time simulated output images. In some embodiments, the deep learning model is trained using training datasets comprising at least a low quality image and a high quality image. In some cases, the low quality image is generated by applying one or more filters or adding synthetic noise to the high quality image to create noise or undersampling artifacts. In some examples, the deep learning model is trained using image patches that comprise a portion of at least a low quality image and a high quality image. In some cases, the image patches are selected based on one or more metrics quantifying an image similarity.

[19] In some examples, the deep learning model is a deep residual learning model. In some examples, the deep learning model is trained by adaptively tuning one or more model parameters to approximate a reference image. In some embodiments, the improved quality image of the subject has greater SNR, higher resolution, or less aliasing compared with the medical image acquired using the medical imaging apparatus.

[20] Another aspect of the present disclosure provides a non-transitory computer readable medium including instructions that, when executed by one or more processors, cause the one or more processors to perform operations comprising: determining an accelerated image acquisition scheme for imaging a subject using a medical imaging apparatus, wherein the accelerated image acquisition scheme comprises one or more parameters related to at least one of an undersampled k-space, an undersampling pattern, and a reduced number of repetitions, and wherein the accelerated image acquisition scheme is determined based on user input and real-time simulated output images; acquiring, using the medical imaging apparatus, a medical image of the subject according to the accelerated image acquisition scheme, wherein the medical image comprises a magnetic resonance image; applying a deep network model to the medical image to improve the quality of the medical image; and outputting an improved quality image of the subject for analysis by a physician.

[21] In some examples, the medical image includes a magnetic resonance image. In some examples, the accelerated image acquisition scheme is determined based on user input and real-time simulated output images. In some examples, the accelerated image acquisition scheme comprises one or more parameters related to an undersampled k-space, an undersampling pattern, and a reduced number of repetitions.

[22] Additional aspects and advantages of the present disclosure will become readily apparent to those skilled in this art from the following detailed description, wherein only illustrative embodiments of the present disclosure are shown and described. As will be realized, the present disclosure is capable of other and different embodiments, and its several details are capable of modifications in various obvious respects, all without departing from the disclosure. Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive.

INCORPORATION BY REFERENCE

[23] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[24] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be

obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings (also “figure” and “FIG.” herein) of which:

CLAIMS

WHAT IS CLAIMED IS:

1. A computer-implemented method for improving image quality with shortened acquisition time, the method comprising:

(a) determining an accelerated image acquisition scheme for imaging a subject using a medical imaging apparatus, wherein the accelerated image acquisition scheme comprises one or more parameters related to at least one of an undersampled k-space, an undersampling pattern, and a reduced number of repetitions, and wherein the accelerated image acquisition scheme is determined based on user input and real-time simulated output images;

(b) acquiring, using the medical imaging apparatus, a medical image of the subject according to the accelerated image acquisition scheme, wherein the medical image comprises a magnetic resonance image;

(c) applying a deep network model to the medical image to improve the quality of the medical image; and

(d) outputting an improved quality image of the subject for analysis by a physician.

2. The computer-implemented method of claim 1, wherein determining the accelerated image acquisition scheme comprises:

(i) receiving a target acceleration factor or target acquisition speed via a graphical user interface, and

(ii) selecting the accelerated image acquisition scheme from a plurality of accelerated image acquisition schemes based on the target acceleration factor or the target acquisition speed.

3. The computer-implemented method of claim 2, wherein selecting the accelerated image acquisition scheme comprises applying the plurality of accelerated image acquisition schemes to a portion of the medical image for simulation.

4. The computer-implemented method of claim 1, wherein the undersampling pattern, a random undersampling pattern is selected from a group consisting of a uniform undersampling pattern, a random undersampling pattern, and a variable undersampling pattern.

5. The computer-implemented method of claim 1, wherein the medical image comprises undersampled k-space image or image acquired using reduced number of repetitions.

6. The computer-implemented method of claim 1, wherein the deep learning model is trained with adaptively optimized metrics based on user input and real-time simulated output images.

7. The computer-implemented method of claim 1, wherein the deep learning model is trained using training datasets comprising at least a low quality image and a high quality image.

8. The computer-implemented method of claim 7, wherein the low quality image is generated by applying one or more filters or adding synthetic noise to the high quality image to create noise or undersampling artifacts.

9. The computer-implemented method of claim 1, wherein the deep learning model is trained using image patches that comprise a portion of at least a low quality image and a high quality image.

10. The computer-implemented method of claim 9, wherein the image patches are selected based on one or more metrics quantifying an image similarity.

11. The computer-implemented method of claim 1, wherein the deep learning model is a deep residual learning model.

12. The computer-implemented method of claim 1, wherein the deep learning model is trained by adaptively tuning one or more model parameters to approximate a reference image.

13. The computer-implemented method of claim 1, wherein the improved quality image of the subject has greater signal-to-noise ratio (SNR), higher resolution, or less aliasing compared with the medical image acquired using the medical imaging apparatus.

14. A non-transitory computer-readable storage medium including instructions that, when executed by one or more processors, cause the one or more processors to perform operations comprising:

(a) determining an accelerated image acquisition scheme for imaging a subject using a medical imaging apparatus, wherein the accelerated image acquisition scheme comprises one or more parameters related to at least one of an undersampled k-space, an undersampling pattern, and a reduced number of repetitions, and wherein the accelerated image acquisition scheme is determined based on user input and real-time simulated output images;

(b) acquiring, using the medical imaging apparatus, a medical image of the subject according to the accelerated image acquisition scheme, wherein the medical image comprises a magnetic resonance image;

(c) applying a deep network model to the medical image to improve the quality of the medical image; and

(d) outputting an improved quality image of the subject for analysis by a physician.