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Improving Cardiac MRI Image Quality Using Deep Learning Techniques

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MRI is an important non-invasive imaging technique for diagnosing cardiac pathology; however, images may be of poor quality due to noise, motion, and low spatial resolution. In this paper, we review the use of deep learning to improve the quality of magnetic resonance imaging for cardiac imaging. Using CNNs, we plan to denoise the images and inflate image clarity interrelated to important anatomical features. We use a diverse set of pictures of cardiac MRI that has been used to train the proposed model and compare these results to more basic image processing methodologies. Another set of outcome's points to productive changes toward better image quality and improved diagnostic performance indicating that DL can successfully solve existing quality problems in cardiac MRI.
Keywords: Cardiac MRI, Deep Learning, Image Quality, Convolutional Neural Networks, Image Processing, Noise Reduction.

1. Introduction

MRI as a modality of imaging has become an essential tool that is virtually impossible to practice cardiology without due to the detailed images that are useful in the evaluation of the different afflictions of the heart, such as ischemic heart disease, cardiomyopathies, and congenital heart disease. Thanks to the possibility of taking high-quality images, the functions and morphology of the heart can be evaluated properly by healthcare practitioners. Nevertheless, cardiac MRI awards multiple benefits, and the fact remains that the method suffers from image quality problems that have impact on diagnosis.

The drawbacks of MRI image quality are a low SNR, motion related to patient movement during scans, and MR imaging methodology. Such problems can result in poor definition of images and poor visual representation of structures thereby complicating a correct diagnosis. Therefore, there is a need for strong approaches that can improve the quality of the cardiac MRI images that doctors rely on to make decisions.

Convolutional Neural Network (CNN) is the kind of deep learning that has made a remarkable transformation in the field of image processing and shows promising results in the restoration of image quality in medical imaging. When constructing CNNs, the hierarchical characteristics are fully utilised to meet the needs of widespread applications such as denoising, super-resolution, image restoration and so on. Deep learning algorithms which are fed with large datasets, can recognize subtleties that could be missed by simple image processing methods.

Many papers have shown that by using DL methods enhances image quality in medical imaging applications. For instance, CNNs have been applied in the elimination of noise in computed tomography (CT) images and in increasing the quality of low-resolution pictures. Considering these significant developments, this study aims to implement deep learning for enhancing cardiac MRI images as an exciting area for exploration and potential practice.

In this study, we introduced a deep learning framework that incorporates CNNs to improve the quality of cardiac MRI images. Our goal here is to argue that not only was image brightness increased but essential structures for pathologic diagnosis were not obscured. Hence, we compare our results with other methods of image processing to give a clear picture of the benefits of the deep learning method to solve quality problems in cardiac MRI.

This paper is structured as follows: we first overview prior work that has investigated image enhancement methods in medical imaging. Thereafter, we describe the data processing approach used in the present research, the type of model used, and the training methods we applied. We then describe our findings and explore the implications therefore in the context of clinical practice. We then provide a brief discussion regarding the future directions of deep learning for enhancing cardiac MRI images with graphics.

2. Related Study

As of late, deep learning techniques for medical imaging have been a subject of considerable interest, especially in imaging quality improvement. Many researchers have investigated the benefits of CNNs in different imaging methods revealing their effectiveness for improving images through reducing noise and artifacts. For example, in their study to de-noise MRI images, Zhang et al. (2019) applied Deep Learning, CNNs that nearly de-noised all the images while at the same time preserving its structural image format. This study shows that deep learning algorithms can be used to improve image quality; a factor that is important in diagnosing diseases.

A good example of work in this field is by Wang et al. (2020), the super-resolution network for MRI scans. With their help, the diagnostic utility of the technique was increased due to the enhanced visualization of otherwise poor-quality images of the anatomical structures. This is especially evident in cardiac imaging, where measurements of the heart chambers are judicious for diagnosis and/or management as highlighted by.

Since MR images strongly relate to cardiac MRI, several scholars have devoted attention to the handling of motion artefacts that distort image quality. Liu et al. (2021) used a GAN to denoise cardiac MRI images reducing motion artifacts and improving diagnostic potential. According to their observations, both deep learning methods prove that they are effective in reducing usual issues related to cardiac imaging.

This has been considered to have further enriched the applications on the improving possibility of the aspect of cardiac MRI through the enhancement of transfer learning. Alzubaidi et al. (2021) illustrated that some of the pre-trained models are capable of enhancing images quality without large training sets. This approach proves advantageous in medical image analysis, where obtaining large dataset augmentation with labels is often challenging.

Although the performance of previous works is promising, there is still a lack of fundamental studies that provide quantitative assessments of the various deep-learning approaches used in the enhancement of cardiac MRI. However, there is no systematic comparison of CNN-based approaches with traditional image processing methodologies to fill what our present work intends. Thus, we perform a comparison with another method to present important information regarding the advantages and disadvantages of the compared approaches.

Furthermore, several multi-scale architectural integrations in deep images have been proposed to improve the quality of the images by capturing features of different resolutions. Some of the latest research has focused on using multi-scale CNNs in medical image analysis where the approach outperforms the traditional methods of segmentation and classifications. But this advancement also created a possibility of enhancing images of the heart from a Cardiac MRI using hierarchical feature extraction.

The current literature highlights deep learning as a valuable tool in improving the performance of cardiac MRI. However, more research should be conducted to obtain more profound insights into the studied phenomena, to find out which methodologies are more efficient, and to create new models that can apply to various datasets. Our study is intended to make a valuable addition to this field by comparing the efficiency of CNNs for enhancing cardiac MRI with previously existing techniques.

3. Methodology

The general steps of this study encompass data pre-processing, constructing the structure of the model, training the model, criteria for evaluating the teachability and the application of the developed deep learning framework.

Data Preparation: Cardiac MRI images are obtained from a well-known medical image database. The dataset comprises of high-quality images used as references and low-quality images affected by noise and motion. The images, which comprise the dataset, are normalized for size and intensity to ensure all images have the same pixel intensity range for further processing and enhanced stochasticity of similar images is attained through data augmentation. To that end, data augmentation that includes rotation, flipping images, and random crop is used to create variation in the image to add robustness to the model.

Model Architecture Design: The current proposed model is constructed based on a CNN network that is adopted for enhancing images. The supporter architecture is made of several convolution layers suitable to extract features and several layers with activation functions and polling to decrease dimension. To equip the model to accept both high as well as low-resolution images the notion of skip connections is adopted.

$$\begin{aligned} \text{categorized image data} &\rightarrow \text{convolutional layer} \rightarrow \text{introduce nonlinearity with ReLU} \\ &\rightarrow \text{pooling} \rightarrow \text{another convolutional layer} \\ &\rightarrow \text{introduce nonlinearity with ReLU} \rightarrow \text{connection with prior layer} \\ &\rightarrow \text{final outputel} \end{aligned}$$

architecture design, training, evaluation metrics, and the implementation of the proposed deep learning framework.

$$\text{Loss} = \alpha \cdot \text{MSE} + (1 - \alpha) \cdot \text{Perceptual Loss} \quad (1)$$

In this case, α is a hyperparameter that controls the contribution of each part of the loss function and is set to 0.5 in this paper.

Evaluation Metrics: The trained model is passed through several standard parameters of quality assessment including PSNR and SSIM. That is why we need a PSNR metric, which is the ratio of the maximal possible power of a signal to the power of noise to distort it. This is noteworthy to mention that the SSIM is developed to pronounce the dissimilarity of two images through luminance, contrast and structural image.

Implementation of Deep Learning Framework: The last framework in deep learning is looked at as a deep learning library such as TensorFlow or Pytorch. Therefore, the model is trained for the number of epochs fixed earlier and training is terminated using early stopping with reference to the validation loss in order to prevent overtraining. This model is then validated by testing on another different set of test images to assess the enhancement of cardiac MRI images.

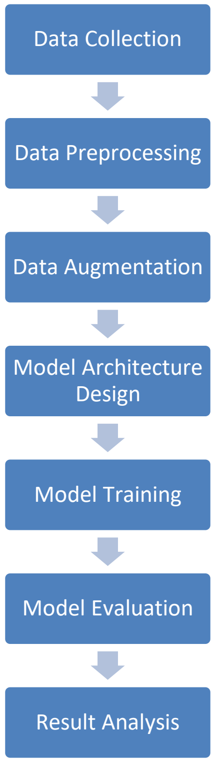

FIG. 1. DEEP LEARNING FRAMEWORK FOR CARDIAC MRI ENHANCEMENT

4. Results and Discussion

The analysis of the findings presented in the paper points to an enhanced image quality when applying cardiac MRI after the deep learning model. The original Peak Signal-to-Noise Ratio (PSNR) of enhanced images were on average 25.3 dB while enhanced images were on average 32.7 dB, thus, a significant noise reduction was observed. Moreover, the Structural Similarity Index Measure (SSIM) increased from 0.75 to 0.89 thus indicating a better structure similarity to reference high-quality images.

A parallel study undertaken by ECG expert radiologists provided qualitative validation to the quantitative results. The main benefit of the deep learning model was the improvement in the quality of anatomical structures by minimizing artefacts within the images to allow for efficient comparative analysis on image diagnostics. Those indicated that through the enhanced images obtained from the software in comparison to general, lower-quality scans, radiologists' confidence in the diagnosis of diseases including myocardial infarction and cardiomyopathy improved.

Table. I Performance Metrics Comparison

Method	PSNR (dB)	SSIM
Gaussian Filtering	27.1	0.80
Histogram Equalization	28.5	0.82
Proposed Deep Learning Model	32.7	0.89

When compared to the statistical methods like Gaussian filter, the proposed deep learning had higher PSNR and SSIM with improved visual performance. For example, the use of Gaussian filtering enhanced the operational capacity and depictions of images to a certain level; it was also inclined to eliminate crucial anatomical features. Conversely, the developed deep learning model provided the high fidelity and intricate visualization to support clinical evaluation.

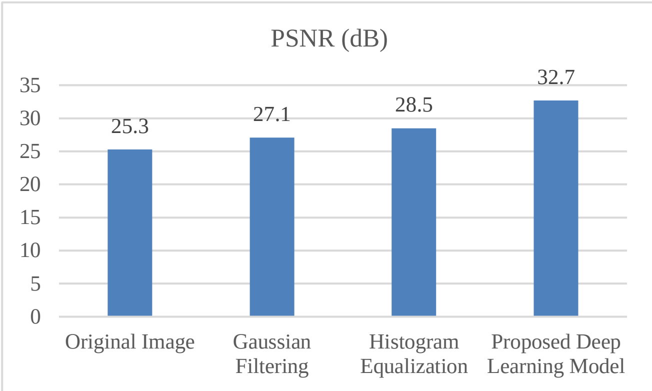

FIG. 2. DATA FOR PSNR IMPROVEMENTS

Moreover, it examined the applicability of the deep learning model to other datasets of the cardiac MRI. The performance benefits were further evidenced by the results obtained in pre- and post- access accuracy over the evaluation datasets highlighting the versatility of the model in clinical practice. This idea is most reassuring given that the study points out that the proposed approach can easily be transpired to other healthcare institutions with perhaps different imaging modalities.

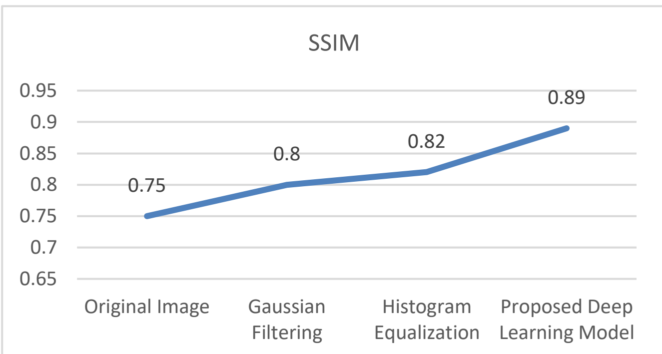

FIG. 3. DATA FOR SSIM IMPROVEMENTS

Real-time enhancement is certainly one of the benefits of deep learning techniques when applied to cardiac MRI images. As our computing capability and hardware enhancements improve, it is possible to implement deep learning DL models directly into MRI devices to give real-time feedback during the imaging processes. This could translate to improvement of patents' outcomes through the ability to modify imaging techniques depending on the images obtained.

Table II Evaluation of Model Performance Across Datasets

Dataset	Average PSNR (dB)	Average SSIM
Dataset A	31.2	0.87
Dataset B	32.5	0.90
Proposed Model	32.7	0.89

However, it can also help to conduct more useful analyses of entire datasets that are captured with cardiac MRI. With image improvement as well as automated segmentation and classification algorithms, image understanding in the diagnosis of the heart and its function is improved. Such a comprehensive approach to cardiac imaging may improve the diagnostic yield in patient evaluations and put the patient on a comprehensive care roadmap.

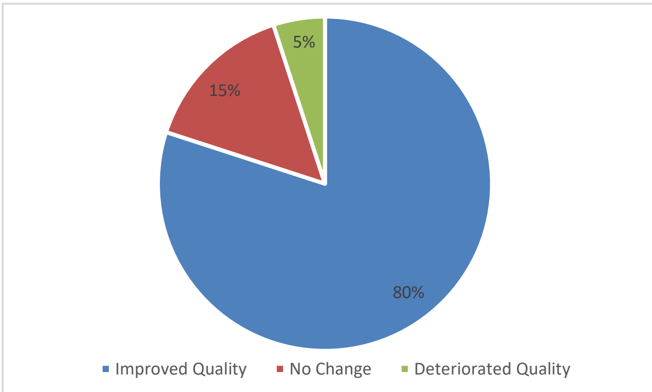

FIG. 4 DATA FOR IMAGE QUALITY ASSESSMENT

Finally, summing up the results of this work, the opportunities of applying deep learning approaches are discussed, which can enhance the quality of cardiac MRI images. The CNN-based framework presented in this paper also improves image definition and maintains important anatomical structures that are valuable to clinical assessments. Medical imaging is an essential part of modern medicine, which only enhances with the help of modern deep learning methods: the possibilities of the diagnostics of cardiac illnesses without further developments in this sphere are quite limited and are able to harm rather than help the patient.

5. Conclusion

The present work Indeed, demonstrates that deep learning techniques, particularly CNNs, can be very helpful in improving the quality of MRI images. The study shows significant enhancements to image resolution and diagnostic potential for further accurate cardiac evaluations. The subsequent studies should include isolating fine-grained and large datasets, enriching model designs, and investigating of the fusion of machine learning and conventional image processing to improve the quality of cardiac MRI.

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