Multi-Channel U-Net (MCUNet) Based Fast and Automated Segmentation for the 3-Directional Multislice Cine Myocardial Velocity Mapping

Yinzhe Wu [a,b], Suzan Hatipoglu [c], Diego Alonso-Álvarez [d], Peter Gatehouse [a,c], David Firmin [a,c], Jennifer Keegan [a,c], Guang Yang [a,c]

[a] National Heart & Lung Institute, Imperial College London, SW7 2AZ, London, UK
[b] Department of Bioengineering, Faculty of Engineering, Imperial College London, SW7 2AZ, London, UK
[c] Cardiovascular Biomedical Research Unit, Royal Brompton Hospital, SW3 6NP, London, UK
[d] Research Computing Service, Information & Communication Technologies, Imperial College London, SW7 2AZ, London, UK

Keywords

Segmentation; Phase-contrast; Myocardium

Background

Three-directional cine multislice myocardial velocity mapping (3D MVM) is a promising CMR technique to reproducibly assessing regional myocardial velocities. In addition to magnitude data, this technique additionally acquires velocity-encoded phase data, which can be used to generate velocity maps in three orthogonal directions throughout the cardiac cycle. Although there are potential clinical applications, the analysis of 3D MVM data can be tedious and may be subjective. While automated segmentation methods on magnitude data have been widely developed, evidence of successful applications in 3D MVM data remains limited.

Method

Our CMR data were acquired at the Royal Brompton Hospital from 9 healthy subjects (two separate sessions, giving 18 datasets in total). In each subject, high temporal resolution (50 frames per cardiac cycle) cine spiral MVM were acquired in a single breath-hold with non-Cartesian SENSE reconstruction and 3 orthogonal directions of velocity encoding.

Inspired by multi-channel processing in biomedical imaging, we developed a Multi-Channel U-Net (MCUNet) based deep neural networks to simultaneously segment both magnitude and phase data from 3D MVM with advanced attention modules. Dice scores were calculated to evaluate the left ventricle (LV) contours (epicardial and endocardial contours) delineated using our automated MCUNet method against the manually segmented ground truth. To compare the velocity curves generated from the manual segmentation and the model-generated delineation, we conducted Bland-Altman analysis.

Results

Cross-validation was performed on 18 datasets, our automated MCUNet segmentation exhibited high Dice scores (Figure 1(a)) with a mean of 0.88. Bland-Altman plot (Figure 1(b)) shows low bias between the two (mean close to 0 cm/s) and small limits of agreement (±1.96 standard deviation(cm/s): 0.27 for the longitudinal, 0.15 for the radial, and 0.14 for the circumferential myocardium velocities). This shows reliability of our MCUNet model. In addition, the trained MCUNet also performed well on further two independent testing datasets (Figure 2(a) and (b)) with a high mean Dice score (0.81) per patient. Their Bland-Altman plots for velocity curves shows low bias (mean close to 0 cm/s) and small limits of agreements as well. The velocity curves plots (Figure 3(b)) also show a close agreement.

For computational efficiency, the developed MCUNet model took ~9 seconds on average to segment each cine slice on an NVIDIA TESLA V100 GPU, whereas the manual segmentation

of both endocardial and epicardial borders of the LV myocardium is a tedious process taking up to an hour for an experienced clinician to complete a single-slice 50-frame study.

Conclusion

In this work, we have assessed and proved that our developed deep neural networks model (i.e., MCUNet) can be applied to segment LV myocardium automatically from 3D MVM data. In addition, the derived myocardial velocities are comparable from those obtained using the manual delineation.

References

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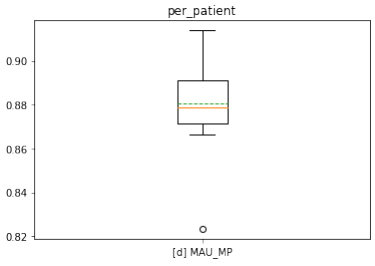
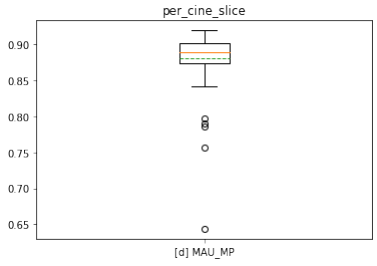
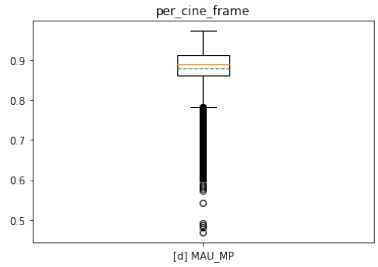
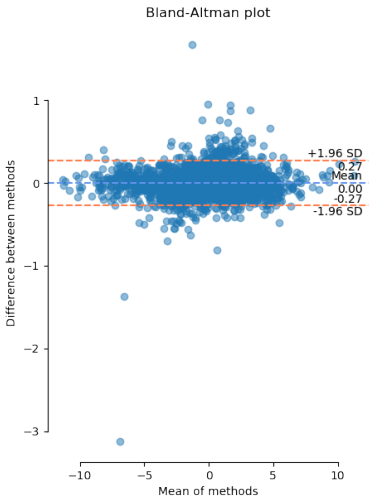
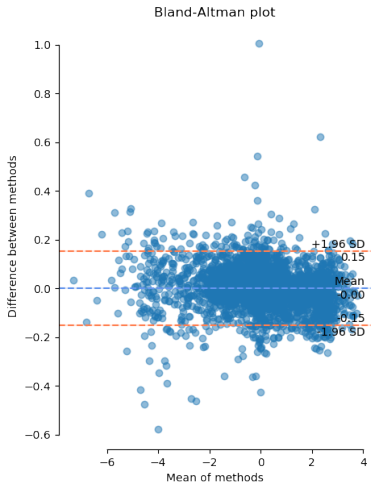
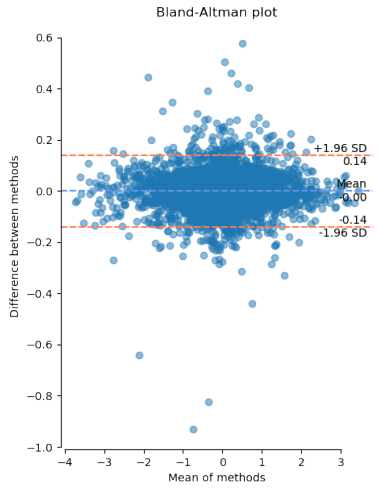
1(a) Dice score box plots			
	Per patient	Per cine slice	Per cine frame
Mean ± std	0.88 ± 0.02	0.88 ± 0.04	0.88 ± 0.05
Box plot			
1(b) Bland-Altman plots for the global velocity curves of the longitudinal, radial and circumferential myocardium velocities per cine slice			
	Longitudinal	Radial	Circumferential
Bland-Altman plot			

Figure 1: (a) Boxplot for the Dice scores per patient, per cine slice and per cine frame and (b) Bland-Altman plot for the global velocity curves of the longitudinal, radial and circumferential myocardium velocities per cine slice.

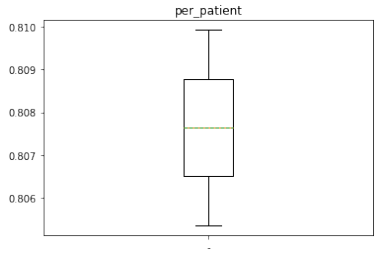
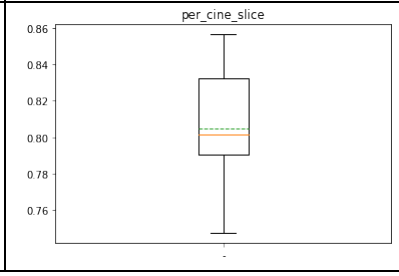
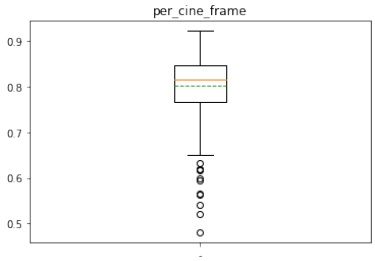
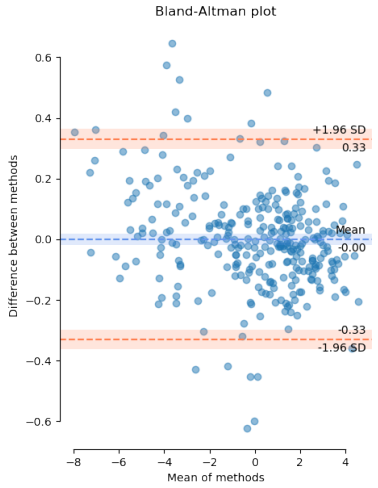
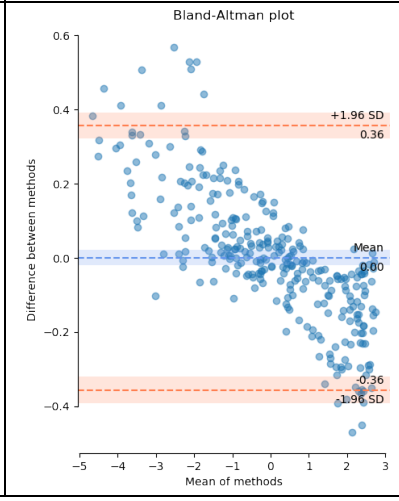
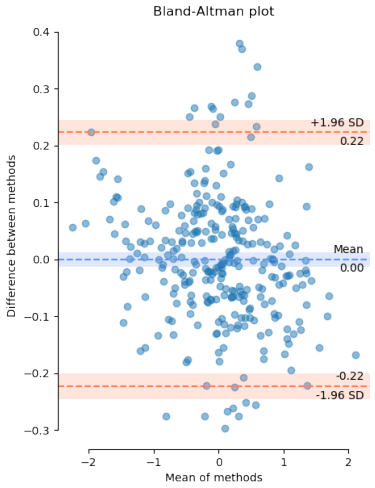
2(a) Dice score box plots			
	Per patient	Per cine slice	Per cine frame
Mean ± std	0.81 ± 0.002	0.81 ± 0.03	0.80 ± 0.07
Box plot			
2(b) Bland-Altman plots for the global velocity curves of the longitudinal, radial and circumferential myocardium velocities per cine slice			
	Longitudinal	Radial	Circumferential
Bland-Altman plot			

Figure 2: Dice scores and the Bland-Altman plots for the independent testing datasets.

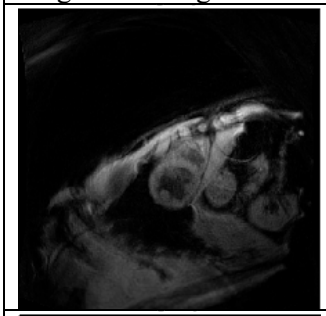
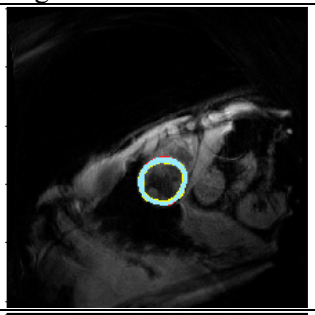
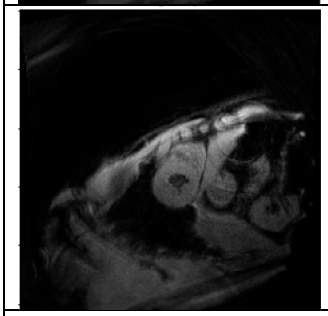
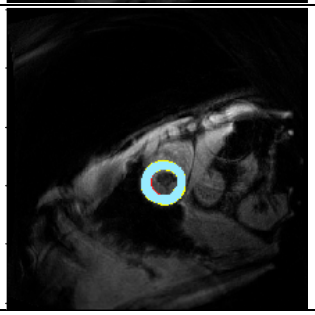
3(a) Segmentation results for sample cine frames

[Segmentation key]

Blue: true positive automated segmentation

Yellow: false positive automated segmentation

Red: false negative automated segmentation

Magnitude image	Segmentation	Dice score per frame
		0.90
		0.94

3(b) Global velocity curves of the longitudinal, radial and circumferential myocardium velocities per cine slice for a sample cine slice from a patient generated from the manual segmentation and our automated segmentation system

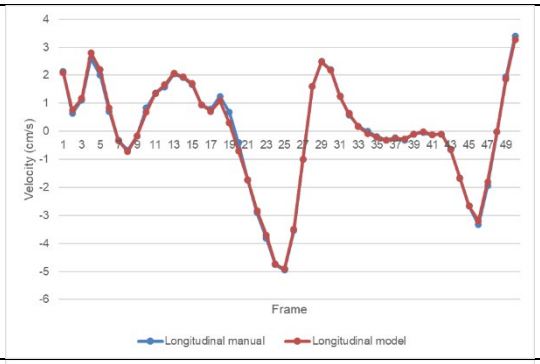
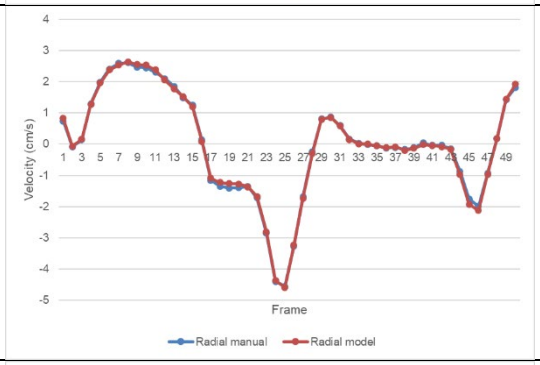
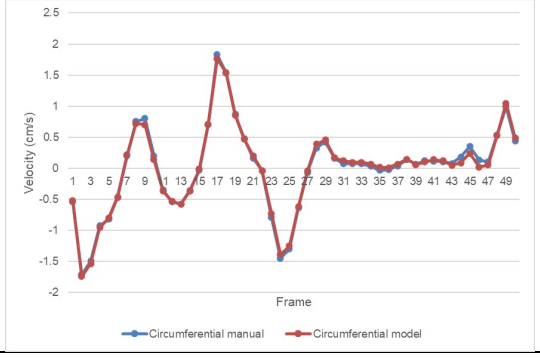
Longitudinal	
Radial	
Circumferential	

Figure 3: (a) Segmentation results for sample cine frames from a patient and (b) global velocity curves of the longitudinal, radial and circumferential myocardium velocities per cine slice for a sample cine slice from a patient generated from the manual segmentation and our automated segmentation system.