Estimating Heart Rate in Echocardiography Patients where ECG Monitoring was not Performed

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ULTROMICS

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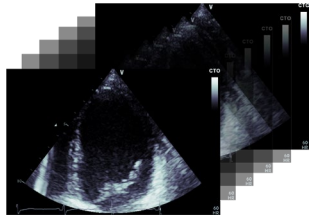
Introduction

In cases of suspected COVID-19, ASE guidelines suggest that ECGs need not be monitored in order to reduce exposure and contamination [1]. However, as some automated methods for cardiac quantification rely on accurate heart rates (HR) being present, it is important to be able to estimate the heart rates in cases where ECG monitoring was not performed. We propose and evaluate several novel heart rate estimation methods that apply directly to echocardiograms of the left ventricle (LV).

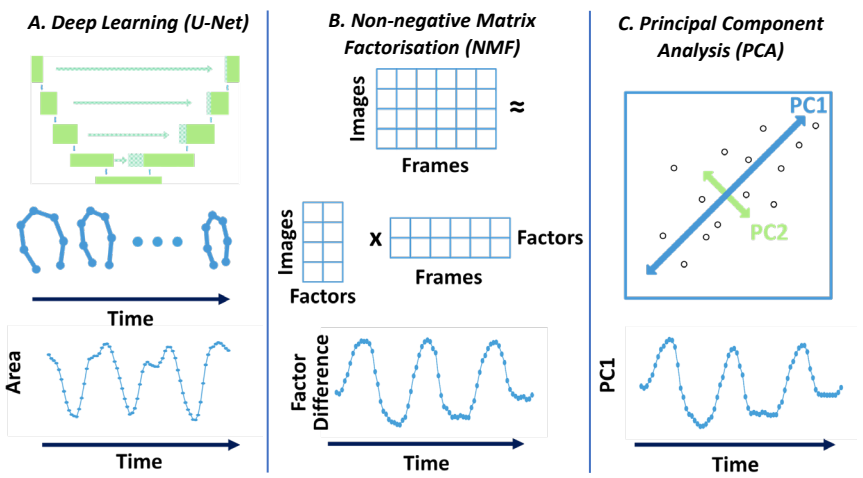
Methods and Results



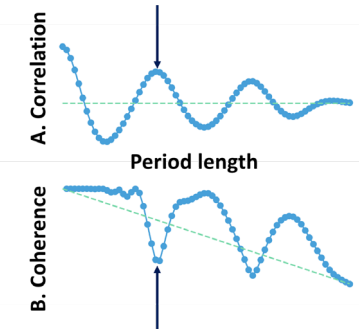
Overview

- A sequence of images is reduced to a one-dimensional time series using one of three different **dimensionality reduction** methods
  - U-Net: A convolutional neural network is trained to segment echo images through time [2]. The segmentation area is the signal.
  - NMF: The images are factorised into non-negative matrices. The differences of these factors is the signal [3].
  - PCA: The images are reduced to principal components, and the magnitude of the first component is the signal.
- The one-dimensional time series is passed through one of two **period extraction** algorithms
- The heart rate is calculated from the period and the time between frames

Step 1. Dimensionality Reduction



Step 2. Period Extraction



- **Autocorrelation** is the cross correlation of the signal with itself, and is widely used in signal processing
- The period is the first local maxima with positive correlation.
- **Coherence [4]** examines the synchronicity of a signal with itself
- The period is the point where the curve deviates most from the significance limit (dashed line)

$$HR(bpm) = \frac{60}{frametime(s/fr) \times period\ (fr/b)}$$

Data

778 DICOM image clips with at least two cardiac cycles, collected from stress echo acquisitions at St George's Hospital, UK, are used for testing. DICOMs encompass a large variety of heart rates, stress echo protocols (both exercise and pharmacological) and view acquisitions (A2C, A4C or SAX-PM).

	Contrast		*Non-contrast*	
View/Stage	***Rest***	***Stress***	***Rest***	***Stress***
A2C	76	80	61	57
A4C	76	80	58	57
SAX-PM	61	63	57	52

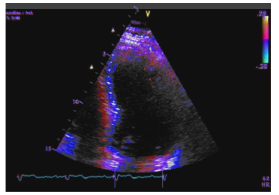
Table 1: Breakdown of View/Stage/Contrast of image clips used

Each combination of methods in each step was applied to each image clip to estimate the heart rate.
The estimated heart rate is then compared to the heart rate encoded into the meta data of each DICOM.
The method fails if a period could not be extracted from the signal.

Failures	***Correlation***	***Coherence***
U-Net	0 (0%)	8 (1%)
NMF	60 (8%)	147 (19%)
PCA	51 (7%)	142 (18%)

Table 2: Number (Percentage) of failures for each combination

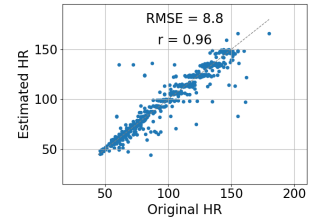
Failures are mostly associated with NMF and PCA. When there is bulk motion during the acquisition, the extracted signal loses its periodicity.

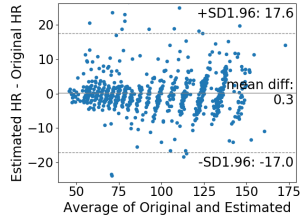


In this example, two consecutive end-diastolic frames are overlaid in red or blue, such that motion of ≈ 1cm is visible

Results

U-net **dimensionality reduction** followed by autocorrelation **period extraction** proved most accurate for estimating heart rate. The results for this combination are shown in Regression and Bland Altman plots below.





Within 20bpm	***Correlation***	***Coherence***
U-Net	97% (753)	96% (744)
NMF	87% (680)	93% (721)
PCA	88% (685)	92% (718)

Table 3: Percentage (Number) of clips with estimated heart rate within 20 bpm of actual heart rate

Within 10bpm	***Correlation***	***Coherence***
U-Net	91% (707)	90% (703)
NMF	82% (637)	89% (691)
PCA	82% (638)	88% (688)

Table 4: Percentage (Number) of clips with estimated heart rate within 10 bpm of actual heart rate

References

[1] Mitchell C, Collins K, Hua L, et al. Specific Considerations for Sonographers When Performing Echocardiography during the 2019 Novel Coronavirus Outbreak: Supplement to the American Society of Echocardiography Statement. J Am Soc Echocardiogr. 2020;33:654-7
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[3] Yuan B, Chitturi SR, Iyer G, et al. Machine learning for cardiac ultrasound time series data. Proc SPIE, Medical Imaging. 2017;10137.
[4] Lindström J, Kokko H, Ranta E. Detecting Periodicity in Short and Noisy Time Series Data. Oikos. 2016;78:406-10

Conclusions

We have developed a robust and accurate method of estimating heart rates from multiple echocardiographic views in the presence or absence of contrast, which works even when there is motion of the probe during the acquisition.

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