Left Ventricle Full Quantification Challenge (LVQuan) in conjunction with the STACOM workshop

Convexity and connectivity principles applied for Left Ventricle segmentation and quantification

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Segmentation in three connected components : LV cavity, myocardium and 'background'
Endocardium and epicardium are nearly convex and smooth curves
The epicardium area variation is small during the cardiac cycle
Thanks to the alignment of the frames, the LV center position variation is small, during the cycle

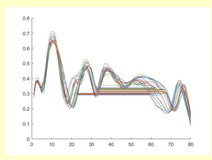
A step-by-step optimization approach is adopted, respecting weak generic constraints and taking high confidence decisions first

Algorithmic steps

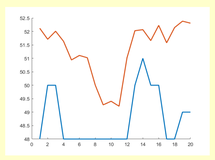
- **LV cavity center positioning and initial LV localization**
- **Final LV localization by adaptive thresholding**
- **LV cavity segmentation based on intensity likelihoods**
- **Background localization**
- **Myocardium segmentation**
- **LV quantification**

LV cavity center positioning

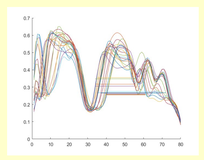
- Gaussian filtering for smoothing images
- Aligned frames in reference to the central frame row
- Adaptive thresholds determined by the intensity minima
- Majority law for selecting location and median value determining the position
- Mean absolute error : 1.54, Median absolute error : 0,99 pixels



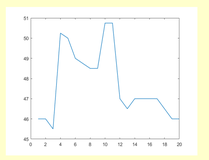
Central row intensity for the whole cardiac cycle



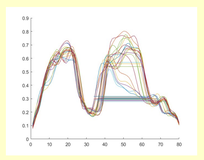
Horizontal coordinate for a subject from the Training dataset



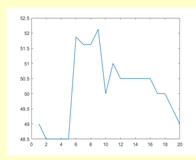
Central row intensity for the whole cardiac cycle



Horizontal coordinate for subject 001 from the Test dataset



Central row intensity for the whole cardiac cycle



Horizontal coordinate for subject 010 from the Test dataset

Initial LV cavity localization

- Homocentric disks of increasing radius
- Almost sure LV classification, if the intensity in the considered disk is above the median value
- Selection of the disk with the maximum median value
- Worst precision rate on Training dataset : 0.95

Final LV localization by adaptive thresholding

- Estimation of mean value of the myocardium and the LV cavity intensity
- Adaptive decreasing thresholds after intensity quantization
- Stop criterion satisfying connectivity and convexity constraints
- Precision rate greater than 0.95 for the 84% of the frames

LV cavity segmentation based on *a posteriori* probabilities

- Estimation of intensity distributions for the LV cavity and the myocardium for the whole frame sequence
- Extraction of a 'closed annular' myocardium class
- Median recall rate for the myocardium near to 0.85
- Estimation of intensity distribution for 'chest space'
- Maximum likelihood / Maximum a posteriori probability classification
- Extraction of the most similar to the localized LV cavity region
- Smoothing using Fourier coefficients
- Median F_1 measure 0.95, mean F_1 measure 0.93

Background localization

- 'Blood' regions in distance from the LV cavity belong to the background
- Large 'chest space' components belong to the background
- With reference to the LV cavity center, extraction of background components in polar coordinates
- Sampling the interior background boundary in angle
- Linear interpolation for missing points
- Find the largest polygon fitting the interior background boundary
- Smoothing using Fourier coefficients
- Median and mean F_1 measure 0.92
- Mean recall rate 0.98 and median recall rate near to 1

Myocardium segmentation

- Initial segment in the septal region
- Adaptive region growing according to the intensity distribution and the connectivity principle
- Extraction of the posible myocardium boundary in the extracted region of interest
- Estimation of the epicardium center
- Fitting a cycle to the relevant boundary
- Growing the cycle according to the intensity distribution
- Smoothing using Fourier coefficients
- Median F_1 measure 0.86, mean F_1 measure 0.84 (myocardium)
- Median F_1 measure 0.96, mean F_1 measure 0.96 (epicardium)

LV quantification

- Areas : pixels counting
- LV cavity dimensions : dense interpolation of the endocardium in polar coordinates in reference to the LV centroid
- Regional wall thickness : in addition dense interpolation of the epicardium
- Phase estimation : from the largest to the smallest LV cavity area

LV localization *Training dataset*

LV localization *Test dataset*

A posteriori probabilities

Myocardium intensity class

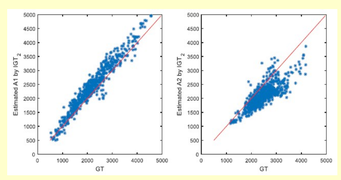
LV segmentation

Background components

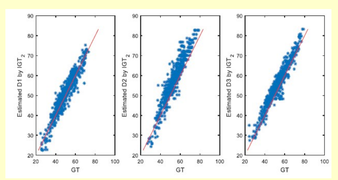
Region of interest

Endocardium and epicardium

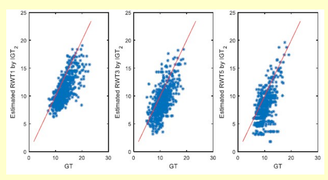
Performance on the Test dataset



	MAE	PCC
A1	250	0.97
A2	395	0.80
Mean	322	0.89



	MAE	PCC
Dim1	2.70	0.95
Dim2	4.65	0.94
Dim3	3.21	0.96
Mean	3.52	0.95

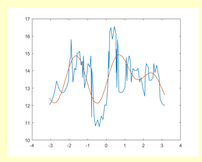


	MAE	PCC
RWT1	2.46	0.72
RWT2	2.01	0.60
RWT3	2.24	0.64
RWT4	1.83	0.70
RWT5	2.33	0.60
RWT6	3.22	0.72
Mean	2.36	0.66

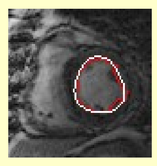
Phase error rate 11.17

Key-modules

Smoothing the endocardium using Fourier coefficients

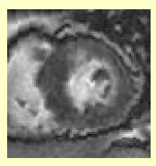


$$\rho(\theta)=b_0+\sum_{n=1}^{N} b_{2n-1}\cos(n\theta)+b_{2n}\sin(n\theta),\ -\pi\le\theta\le\pi$$

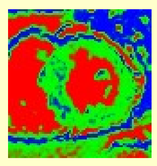


Area conservation *N=3*

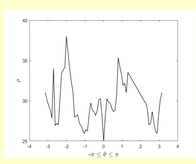
Region of interest extraction from the background components



A posteriori probabilities



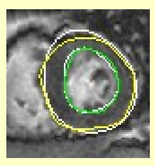
Background components



Sampled radius

Minimum polygon

Region of interest



Result and *Ground truth*

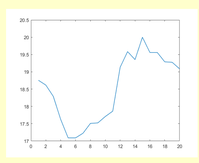
Myocardium segmentation

Myocardium *Septal region*

Intensity distribution

Homogeneous segment

Boundary

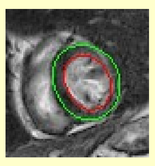


Minimum radius

First annular segmentation

Region growing

Smoothing



Final segmentation

Computation time : laptop Intel Core i-7 2.6 Ghz, Matlab
Approximately 2 secs per subject for a cardiac cycle of 20 frames 80 x 80 pixels

Possible improvements, future directions :
Learning of the hyperparameters
Adaptive processing of inhomogeneities
Stage of myocardium / LV cavity separation
Time coherence