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Applying Deep Learning Techniques in Automated Analysis of Echocardiograms, CMRs and Phonocardiograms for the Detection and Localization of Cardiac Diseases

Authors:

Arvind Bansal and Racheal Mukisa

Kent State University, Kent, OH, USA

Emails: akbansal@kent.edu and rmukisa1@kent.edu

Presented by Racheal Mukisa

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Short Bio of Racheal Mukisa (Presenter)

- PhD student of Computer Science at Kent State University
- PhD Advisor: Professor Arvind Bansal
- PhD Research area: Applying Deep Learning Techniques to Analyze Cardiac Defects
- Recipient of AAUW (American Association of University Women) Fellowship and Kent State Graduate Assistantship

Research Interest of the Group

- Social Robotics
  - Facial expression analysis
  - Gesture analysis
  - Gesture generation in humanoids
  - Multimodal analysis of human emotions and pain
- Intelligent analysis of Biosignals
  - ECG analysis
  - Cardiac echogram and MRI analysis using deep learning analysis
- Intelligent analysis of micro-RNA targets to understand human disease such as cancer

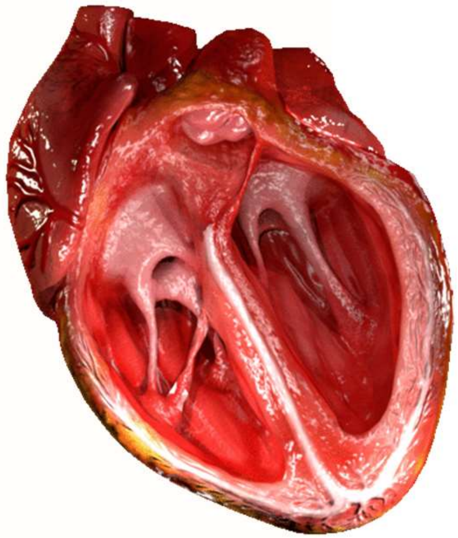
Motivation

- Overall review of the current trends in applying deep learning techniques to understand and localize cardiac defects
  - Analysis of echoCG (echocardiograms) images using CNN, LSTM and their combination
  - Analysis of Cardiac Magnetic Resonance (CMR) images and video frames using CNN, LSTM and their combination
  - Analysis of phonocardiograms (PCG) using CNN and LSTM to detect valvular diseases and fetal cardiac defects
- Automated analysis combining deep learning techniques is a powerful approach due to
  - Non-invasive nature
  - Blood flow related analysis using Doppler echoCG
  - Improved resolution of images with reduced cost, especially for echoCG

Contribution

- A good comprehensive reference article describing various cardiac diseases involving cardiac muscle defects and valvular defects
- Describes the issues in cardiac chamber and valve detection using image segmentation
- Describes the application of deep learning in identifying
  - Cardiac wall detection
  - Blood-flow volume detection
  - Cardiac wall thickness in ventricle under continuous cardiac motion
  - Wave pattern analysis of PCG

Background – Anatomy of Heart

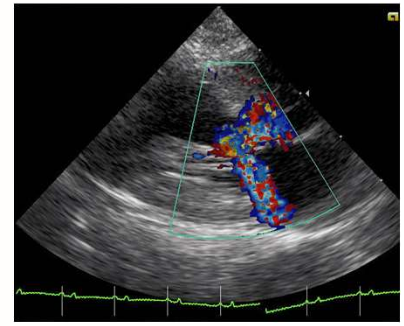


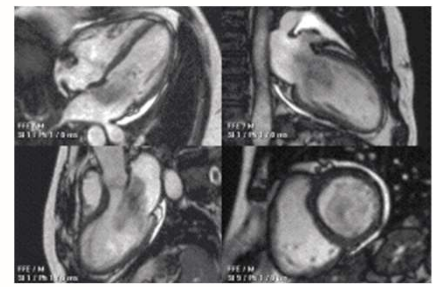
- Four chambers:
  - Right atrium (RA); right ventricle (RV);
  - Left atrium (LA); left ventricle (LV)
  - Left chambers are separated from right chambers by septum
  - LV is the biggest chamber
- Blood-flow: Body → RA → RV → Lung → LA→ LV→ Body
  - Compression/relaxation occurs due to bioelectric signal flowing in cardiac cells
  - Periodic compression of upper and then lower chambers
  - Compression in upper chambers moves blood from upper → lower chambers
  - Compression in lower chambers pushes blood to lung or body
- Valves to control blood flow
  - Tricuspid valve (3 leaflets): RA → RV;   pulmonary valve (two leaflets): RV → lungs
  - Mitral valve: LA → LV;   Aortal valve: LV → body

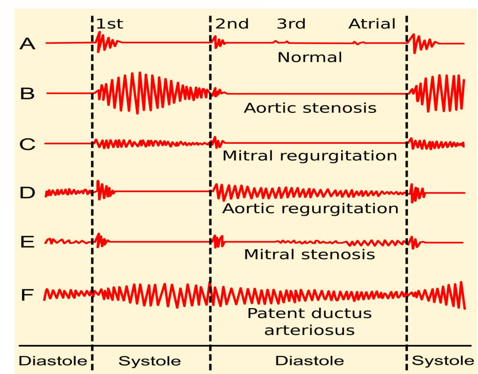
*The image is taken from Wikimedia commons and is in public domain

Noninvasive Techniques

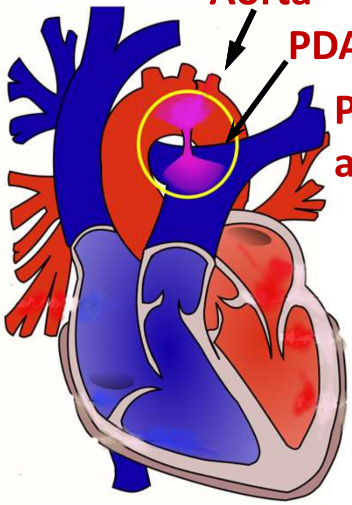
- Echocardiogram (echoCG)
  - Ultrasound technique using reflection and refraction using millimeter waves
  - Resolution has improved significantly
  - Two types of echograms: TTE (transthoracic echoCG) and transesophageal echoCG (TEE). TTE is completely non-invasive
- Cardiac Magnetic Resonance (CMR)
  - Uses MRI-based imaging of heart
  - Based upon relaxation of magnetically excited hydrogen ions
  - Uses multiple 2D slices to simulate 3D images
  - Best possible resolution among imaging techniques
- Phonocardiograms (PCG)
  - Sound recordings of continuous opening and closing of valves
  - Not suitable for localization of muscle-based and valvular diseases







Valvular and Heart Muscle Diseases



- Cardiac hypertrophic myopathy
  - Increased muscle thickness and reduced ventricular volume
  - Blood volume flow problem and hypertension
- Valvular diseases causing stenosis and regurgitation
  - Calcification of the leaflets and defects in valves
  - Ebstein's anomaly: restricting blood-flow to lungs
- Diseases caused by chamber or blood-channel fusion during birth
  - Blood contamination between de-oxygenated and oxygenated blood
- Perforation or hole in the septum during birth
  - Blood contamination between deoxygenated and oxygenated blood
- Narrowing of blood channels due to deposits causing ischemia, myocardial infarction, or blood-flow problem

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Issues and Advances in Diagnosis

- Invasive investigations for diseases based upon cardiac muscle, chamber or valves are expensive and have side-effects
- ECG can only analyze the presence of arrhythmia, indicate ischemia, myocardial infarction, or electrolyte deficiencies.
  - Cannot localize the diseases caused by defects in cardiac muscle, chamber or valves
- Defects in cardiac muscle, chamber or valves require 3D image analysis, motion analysis and blood flow analysis
- Echocardiogram and CMR provide information about images and motion needed for localization
- PCG provides information about regurgitation and stenosis

Deep Learning in Diagnosing Cardiac Diseases

Disease Class	Input Mode	DNN Technique
Valvular stenosis + regurgitation	echoCG and PCG	CNN-based segmentation and TGNN + CNN + LSTM
Fetal heart defects	echoCG + CMR	CNN-based segmentation for wall boundaries
Myocardium hypertrophy and myopathy	Doppler echoCG + CMR	Hybrid CNN + LSTM + encoders and decoders for wall thickness, chamber boundaries and blood flow volume
Ischemia and myocardial infarction	CMR	CNN based tissue classification

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Echocardiogram Analysis using Deep Learning

- Used to diagnose
  - Stenosis and regurgitation; atrial blockages including atherosclerosis; atrial fibrillation; congenital heart disease; coronary arterial disease; cardio myopathy and hypertrophy; murmur
- Used CNN + LSTM and their variants for segmentation
  - Segmentation is measured using non-isotropic diffusion
  - Aorta and mitral regurgitation uses region-based CNN, jet-area ratios, jet-stream acceleration at orifice, and PISA
  - Area of the orifice is estimated using blood-flow convergence and Doppler's effect
- CHD estimated using multiview echoCG and depth-wise separable convolution
  - Filters and combines two separate layers reducing computational complexity
  - Multiview provides clarity and evidence from other views

Issues and Approaches in EchoCG Analysis

- Major problems in chambers identification
  - Artifacts
  - Discrimination between chambers and septum using similar light intensity
  - Fixing missing boundaries between chambers when valves are open
- Multiple variants of CNN-based models
- DW-net derives boundaries precisely using two layers
  - Dilated convolution change (DCC) layer collects local and global features
  - W-net derives precise boundaries using repeated encoders + decoders
- Echonet derives precise structure and anatomy of heart, blood-flow volume, chamber enlargement, hypertrophy, etc.
  - Uses multiple attributes: age, sex, gender, blood flow volume, LV hypertrophy, pacemaker, LA enlargement, etc.

Deep Learning based CMR Analysis

- Cardiac region is identified using dynamically changing voxel intensities
  - LV is recognized first being the largest chamber
  - Other chambers are recognized later using a heart model
- Dynamic chamber shape estimation
- CMR analysis estimates end-diastolic-volume (EDV), end-systolic volume (ESV), ejection fraction (EF), and myocardial mass
  - Quantification is used to estimate blood-flow and blood-ejection from LV
- Segmentation approaches used for muscle defects and valvular defects
  - Approaches are image driven or model driven
  - Image driven approaches use intensity-based histogram analysis, clustering, region growing, and active contours to identify blood pools
  - Model driven approaches use statistical analysis with atlas or shape contours
  - LV segmentation is used for motion estimation, wall thickness, ischemia and infarction

Phonocardiogram Analysis

- Analysis is based upon diastolic and systolic phases
- Estimates stenosis, regurgitation, atherosclerotic disease and murmur
- Analysis is done either in time-domain or frequency domain
- Time domain analysis uses wavelet transforms + deep learning
- Frequency domain uses Fourier transforms + deep learning
- Time-growing Neural Network (TGNN) for deep learning
  - Divides the waveform in multiple time segments and diastolic and systolic patterns
  - Combines windowing with neural net-based classification
  - Windowing uses a fixed starting point by growing end-point
  - CNN + LSTM based hybrid model is used for the classification of diseases

Major Datasets

- EchoNet Dynamic Database
  - Includes 10330 four chamber videos with human expert annotations
  - Includes measurements, tracings, ejection volume and cardiac motions
- Creatis Database contains multimodal 2D and 3D echoCG and CMR images, application software and diagnostics
  - It contains smaller databases including simulated sequences, manual contouring of LV and RV
- Harvard Database: CMR 4D blood flow datasets of echoCG and CMR data of 108 patients
- Tuft Medical echoCG dataset contains information about disease severity
- Heart Database contains 3D CMR segmented LV images validated by clinicians
- EMIDEC Database contains CMR LV images of 150 patients with heart attacks
- Physionet Database contains nine PCG datasets
- Cardiac Atlas Database contains pathological datasets of regional heart shapes

Discussion and Conclusion

- Review has provided recent trend in applying deep learning for noninvasive image-based analysis of heart muscles defects and valvular defects.
- The analysis combines information from echoCG images, Doppler effect-based blood-flow analysis, CMR multimedia images for heart chambers and PCG-based sound analysis.
- The integrated deep-learning + image-based analysis can detect
  - Heart chambers detection, motion analysis, heart wall thickness, blood-flow estimates
- Many diseases previously not detected or localized noninvasively can be detected and localized accurately and noninvasively.
- In the coming decade, deep learning-based analysis will become part of effective localization of heart defects.