

CAVITY SEGMENTATION AND STROKE VOLUME MEASUREMENT METHODS FROM ECHOCARDIOGRAPHIC IMAGES: REVIEW

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Received 2014-05-06; Revised 2014-06-15; Accepted 2014-11-10

ABSTRACT

The complexity and criticality of heart disease diagnosis and treatment have frequently attracted the attention of researchers to develop approaches that can handle accurate clinical assessments. One of these complexities is measuring the Right Ventricle stroke volume. Therefore, different cardiac imaging techniques have been developed to help specialists in their regular clinical work and in the operating theatre to assist in the diagnosis, monitoring of the treatment and to ensure the success of a cardiac intervention as far as possible. Echocardiography is one of the cardiac imaging techniques and is considered as the most effective imaging technique as it is minimally invasive, quick and the cheapest method. Many studies have been conducted on Right Ventricle assessment from echocardiographic images. This review is aimed at presenting the previous technical elements and algorithms used to measure the ventricle stroke volume from echocardiographic images. The review focuses on the five technical approaches that have been used, which are pre-processing, End-Diastolic (ED) and End-Systolic (ES) frame detection, cavity segmentation, the stroke volume measurement and 3D reconstruction. Finally, a summary will conclude this study.

Keywords: Echocardiography Image, Stroke Volume, Right Ventricle (RV), Left Ventricle (LV), End-Diastolic (ED) and End-Systolic (ES), Three Dimensional Echocardiography (3DE), Pre-processing, Segmentation, 3D illustration, Cloud Point Orientation

1. INTRODUCTION

This study presents the review of the approaches utilised in steps of an algorithm presented by (Argones *et al.*, 2008; Rahmat *et al.*, 2013), as a part of research work for cavity segmentation from four Dimension Echocardiographic images (4DE) to measure the Right Ventricle (RV) stroke volume as a part of PhD thesis in University Putra Malaysia. The paper starts with

a block diagram to show the sequence of approaching in the literature review, as illustrated in **Fig. 1**.

2. PRE-PROCESSING

Although the development of the medical imaging techniques and its equipment's and the improvement of the imaging resolution. Pre-processing is still the core the primary step in the medical image processing

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algorithms. This section of the literature is focused on the pre-processing methods performed on echocardiographic images. These methods are performed using simple step (s) or hybrid methods for image enhancement, data size reduction, or processing time reduction.

Echocardiography is a test that uses ultrasound to generate moving pictures of the heart, Bonow *et al.* (2012). Since ultrasound images can be affected by many factors such as speckle noise, motion artifacts. Dawood *et al.* (2011) pre-processing is required to obtain high performance in scheme extraction, information retrieval, storage cost reduction, processing time reduction.

Different image enhancement techniques are used to improve the quality of echocardiography images. These include filters, which are used in many studies for image enhancement in the pre-processing stage. High boost filtering was used to enhance high frequency components without affecting the lower frequency components, followed by morphological opening and closing, to reduce the speckle noise. Then, the negative Laplacian filter was used based on kernel convolution for regional filtering to eliminate small contours for the extraction of the intracardial cavity of LV in short axis view images. Sigit *et al.* (2009a) used a median filter, morphological opening and contrast enhancement to segment the LV contour, then edge detection and image combining for explicit detection. In another study, (Hussein *et al.*, 2009; Lacerda *et al.*, 2008) used a sequence of steps, namely firstly using high-boost filtering, then thresholding and then a Laplacian of Gaussian (LoG) filter for image enhancement in a study to segment the LV cavity. Histogram equalization and an adaptive median filter were used for image enhancement by Deka and Ghosh (2006) followed by morphological dilation and erosion with a group of directional structured structuring elements.

In another study for the segmentation of LV in echo images was done by Santos *et al.* (2007). Their pre-processing method reduced the data size and processing time through cropping image regions into fixed sizes and then dividing the image into rectangular blocks. The Otsu threshold was then computed for each block and background subtraction was performed.

Frame-based pre-processing is another type of pre-processing approach that can assist in verification performance Argones *et al.*, (2008). Revell *et al.* (2003) also stated its suitability for feature extraction, specifically to extract the contour of the tendon by creating a composite frame from 20 sequential images. Then, the composite and single frames were subtracted before binarizing the image using empirically determined

thresholds to reduce data size. Kondo *et al.* (1995) used frame-by-frame subtraction to indicate the motion in their assessment of the delayed onset of the LV, where 60 frames/sec echocardiographic images were used. Amorim *et al.* (2009) used fused three frames in equivalent positions of three cardiac cycles as the first step of pre-processing to enhance LV wall construction and for noise reduction. Then, smoothing and thresholding were applied to improve the segmentation performance.

From this literature we can conclude that the pre-processing can be performed in different methods based on the objective, such as image enhancement which may be used to reduce the noise effects and video frame processing to reduce computation time, feature detection, or it can be used for motion tracking.

3. RV SEGMENTATION

Object segmentation is a very important stage in medical image analysis because it affects the assessment accuracy. Boundary detection approaches are among the most frequently used methods for segmenting the cavity in echocardiographic images.

To the best of our knowledge, automatic RV cavity segmentation has not been reported in the literature. Existing approaches required manual initialization of boundary points. This is followed by smooth curve fitting through those points to generate the boundary. Most of the literature deals with cavity segmentation for LVs.

Boundary detection is one of the most frequent methods used to determine the organ feature (Hussein *et al.*, 2009). However, proper detection of boundaries in echocardiography images is difficult due to speckle noise, poor image quality and artifacts caused by intra-cavity structures. Therefore, pre-processing is an important stage in feature extraction for echocardiography images. The pre-processing stage can influence the accuracy of ROI segmentation as well as the time cost of boundary extraction Santos *et al.* (2007).

The work by Friedland and Adam (1989) used prior-knowledge of the geometry of organs to determine the LV cavity, which was considered a fast boundary detection technique. Firstly, low-pass filtering was performed for decimation to reduce the data size and manual rough estimation of the ROI position. A global optimization approach was taken by computing an energy function to determine the suitable edge region. Then, used simulated annealing used to extract the LV boundary.

The initial determination of the ROI position and fuzzy center point estimation of LV at the long and

short-axis views of a sequence of images from one cardiac cycle was proposed by Setarehdan and Soraghan, (1996) in the first step for boundary extraction of the LV. In the work, the initial boundary points were defined based on the global maximum point of wavelet transformation to defined the candidate points of the cavity boundary, Upon defining the candidate points Cubic B-Spline was employed to generate the smooth LV boundary through these points. The center point and rough locations of endocardial and epicardial boundaries were determined based on the elliptical shape of the LV. The endocardial and epicardial boundary were extracted in sequence of short axis LV images by wavelet-based edge detection approach. Then, the boundary was closed using a local smoothing filter to generate a close smooth boundary Laine and Zong (1996). However, this method failed to extract the boundary from poor quality images. Mishra *et al.* (2003) used morphological opening and closing with low-pass filtering to optimize the initialization of the genetic algorithm to determine the LV boundary. Santos *et al.* (2007) presented a fast boundary extraction of LV cavity from long axis view image. Linear stretching of histogram was used for image enhancement. Then, the image was divided into blocks before converting each block into binary images using local Otsu thresholding. Finally, a cubic spline interpolation was used to generate smooth boundaries.

An automated coupled deformable model was used for segmenting the myocardial borders of the LV from RT3D echocardiographic images. This approach was originally proposed by Zhu *et al.* (2009). It incorporates the incompressibility property of the myocardial and therefore is able to handle the fuzzy epicardial borders. This model maximizes the regional homogeneities of a cardiac image, while maintaining the myocardial volume during a complete cycle. By simultaneously evolving both endocardial and epicardial boundary surfaces, an automatic segmentation of the full myocardium is achieved from RT3D echocardiographic images.

Qin *et al.* (2013) presented automatic segmentation for RV from four chamber view in 2DE images, the RV location is detected automatically using training system. The first step of the algorithm was analyzing the statistical information of the images using Sparse Matrix Transform (SMT) to detect the cardiac motion. Secondly, built training model to determine the location of the RV, based on cardiologists' determination of the epicardial and endocardial of the RV cavity on 450 images. Third, the training model was then adjusted as an adapted initialization for the segmentation of each image in the series of one

cardiac cycle. Finally, a localized region based level set algorithm was applied based on the adapted initializations, for segmenting the epicardial and endocardial boundaries of the right ventricle, from the whole series of one cardiac cycle images.

Watershed transformation is one of the segmentation methods used to segment the LV cavity. Deka and Ghosh (2006) presented a method to segment the LV cavity in ultrasound image, their approach started with histogram equalization, an adaptive median filter used in pre-processing stage and multiscale morphological gradient method, for image enhancement to achieve better segmentation. The next step was, performing the watershed segmentation method to segment the LV cavity. Finally, they merged the neighbouring regions according to the similarity in region size. The over-segmentation problem was the main limitation of this technique. Therefore, Ng *et al.* (2008) aimed to reduce the over-segmentation based on texture and size criteria by computing the angular scan moment, contrast, entropy and inverse difference moment to generate the regional texture map. They computed each segmented region's area to determine the threshold value of each area. Finally, a merging process was applied according to the texture similarity and threshold of region size.

Lacerda *et al.* (2008) used watershed segmentation to classify the 2D echocardiographic image of the LV to small regions and then these small regions were merged based on empirically identified thresholds of region area of 150 pixels. Next, radial search was used to select the candidate points of the ventricle boundary, short distance interpolation followed by morphological closing to generate the smooth contours.

Sigit *et al.* (2009b) introduced a boundary segmentation method for the short-axis view of the LV. They began with a high boost filter for image enhancement to reduce the higher frequency components retaining the lower frequency components. This was followed by applying morphological and thresholding operations to eliminate noise and convert the image into binary format. The third step applied the negative Laplacian filter for edge detection. The fourth step was region filtering to eliminate small regions. The last step involved detecting and reconstructing the imprecise border using triangle equation.

Two stages of operation were performed by Junier *et al.* (2008) to segment the boundary 2D echocardiographic image of the long axis view of LV. In the first stage, images fusion was applied to a sequence of images, followed by smoothing and Otsu thresholding were performed to identify the ROI. Then, the second stage,

consisted of watershed segmentation to determine the ROI, followed by a multiscale gradient operator to identify the edge of the eroded, the inner and outer boundaries were then determined after filling the regions. This was followed by calculating the Euclidean distance of each region. Finally, watershed segmentation was applied for the image resulted from the Euclidean distance transformation to extract the LV boundary.

Hao *et al.* (2000) used region growing segmentation for myocardium assessment. Images were classified into classes of gray levels based manually determined points on the myocardium. The myocardium was then segmented into regions using the information characteristics (which represented by characteristic vectors of classes and characteristic vectors of pixels) and geographical similarity of pixels. Mancas *et al.* (2005) proposed a method to segment the ultrasound images by manual determination of the initial seed point. Subsequently region growing was performed by thresholding the images using a gray space map. Another approach for seed point detection of breast tumour segmentations was presented by Shan *et al.* (2008) based on a pre-determination of the ROI. In this approach, the center point of the ROI was selected as the seed point. According to the literature reviewed in this field, it can be pointed out that, the seed point detection process in most of the method depends on the pre-determination of the ROI, enhancement of the images and a feature description of the segmented ROI (lesion).

As manually selecting seed points can be cumbersome, some studies have proposed automatic seed point detection, such as (Koo *et al.*, 2009). They assumed the pixel value of a tumour image, after undergoing image enhancement, is close to zero. K-means clustering was used for automatic detection of the seed point, thus the grayscale value of the pixels (which assumed to be closed to zero) for the tumour region and the coordinate of the image pixels were considered for the K-mean.

4. END-DIASTOLIC AND END-SYSTOLIC DETECTION

Accurate detection of the End-Distally (ED) and End-Systolic (ES) stages of a cardiac cycle is a significant factor that can affect the accuracy of abnormality assessment of a ventricle (Ostenfeld *et al.*, 2012; Darvishi *et al.*, 2012). This process is a routine step of the ventricle assessment procedures, where often, in clinical reports, many parameters can be measured in these two stages to help in diagnosing and decision making Barcaro *et al.* (2008). However, the process of

detecting the ED and ES still a challenge for diagnosis because it was mostly done manually by tracking the cine loop during the clinical procedure, as in Niemann *et al.* (2007) or by optical tracking of the change of ventricle dimensions through watching the individual image faces of the ventricle during the cardiac cycle, as in (Aune *et al.*, 2009; Crean *et al.*, 2011).

Tracking the mitral valve motion is another method for detecting the ED and ES frame, where the ES stage is defined as the last frame before the opening of the mitral valve while the ED stage is the last frame before the closing for the mitral valve, as reported by Nosir *et al.* (1996). In the meanwhile, tracking the mitral valve together with the ventricle volume was presented by Barcaro *et al.* (2008). ECG signal was used by Zhu *et al.* (2009) to determine the ED and ES frame of the LV in order to generate a dynamic model of the (Gopal *et al.*, 2007; Chua *et al.*, 2009) also used ECG to determine the ED frame through the R wave of the ECG and the ES frame was determined as the smallest cavity area. The biggest and smallest area of the RV cavity were visually tracked in three views; short axis, four chamber and coronal by Ostenfeld *et al.* (2012) to determine the ED and ES cardiac stages.

Gifani *et al.* (2010) presented an automatic detection method for ED and ES of LV from two and four chamber views using unsupervised learning algorithm Locally Linear Embedding (LLE) for three cardiac consecutive cycles. Shalbaf *et al.* (2011) performed image registration for echocardiographic images of 6 volunteers, distance computation and finally the classical Multi-Dimensional Scaling (MDS) used to construct low dimensional representation of 2D LV images to generate Iso-map. Then, they computed manifold model of seven phases of cardiac cycles to determine ED and ES stages automatically.

Tsui *et al.* (2013) determined ED and ES stages by tracking the mitral valve motion, based on Nosir *et al.* (1996)'s definition for the ED and ES stages. This method used 3D echo image of LV, by binaries and enhancing images in the pre-processing stage of their algorithm. Then, a dilation operation for different resolution scale was performed to avoid the blood flow effect. Finally, the number of connecting regions for 8-neighbors connectivity was computed. This method gives accurate results only with good quality echo image of mitral valve.

All of previous methods in this section are time consuming; therefore, an accurate automatic detection for the ED and ES stages is highly required to assist specialists and interns in their clinical work.

5. RV VOLUME MEASUREMENT METHODS

Although, the first historical description of the RV arrhythmic disease was in 1736 by G.M. Lancisi, when he reported the disease in a family recurrence in four generations Basso *et al.* (2009). The first electrocardiographic description of the RV disease was in 1961, two cases reported by Sergio *et al.* (1961) for auricularisation which is “the right ventricular pressure curve” and the main pulmonary artery pressure through the characteristic epsilon wave. Since then, the disease has been noted as the main cause of sudden death in youth and particularly in athletes Fontaine and Frank (1984).

Later, cardiac imaging techniques such as MRI, CCT and echocardiography are developed to visualize moving heart structure and provide a wealth of information and measurements. Echocardiography is one of these techniques, which became one of routine clinical tool for diagnosing, assessing, pre-operation planning and treating. There are many studies presented to assess the RV volume and function.

Levine *et al.* (1984) pioneered the assessment when they measured the RV volume of latex model using the apical four-chamber view and subcostal RV outflow tract view. The endocardial boundary determined by Microsonic computer and the disconnected boundary joined by straight lines. The measurement was done by measuring the area of one viewing plane (A_1) and the length of the longest axis (L_2), then the volume was computed by the mathematical relation Equation (1):

$$V = c \times A_1 \times L_2 \quad (1)$$

where, c is a constant.

Meanwhile, (Starling *et al.*, 1982; Helbing *et al.*, 1995) used Disk Summation Methods (DSM) or Simpson rule to measure the RV volume, for a predominantly four-chamber view in 2D images, the Ventricle Outflow Tract (RVOT) was excluded from the volume. Therefore, this method gave an underestimated volume.

RV apical four chamber view is considered by Foale *et al.* (1986) as the best view that could be used to defined the apex and the tricuspid valve of the RV, in their study to assess the right ventricular function from the area of the RV at the ED and ES frames, using off-line computer system produced by Microsonics Company. The ED and ES frames were identified by the closure and opening of the tricuspid valve.

Area-length methods is another method used with 2D echocardiography images. This method requires

geometrical approximation of RV structure based on ellipsoidal or modified pyramidal model after manual determination for the intracardial boundary Leng *et al.* (1994). As it was reported in many previous researches, the results of measuring the RV volume in 2D images were not accurate, while this method is based on geometrical assumptions; therefore, it is very sensitive to the imaging plane and angle. Recently, the Three-Dimensional Echocardiography (3DE) technology, utilized fully sampled matrix array transducers with live 3D mode. This technology displays a pyramid of 3D images of the cardiac scheme and allows a complete visualization of the entire myocardium (Vegas and Meineri, 2010), those 3D image scans be obtained from a single acquisition using one wide imaging mode for one cardiac cycle or from several consecutive cardiac cycles using four or seven narrow neighbored angles. The improvement in 3D imaging comes from the availability and accessibility to RT3DE. However, RV size and function quantification remains clinically difficult despite of the advanced cardiac imaging.

There are many researchers who published their works on measuring RV volume using 3D techniques. Among these are Aune *et al.* (2009), who used QLAB and applied Left Ventricle (LV) measuring method, by determining four landmarks at the tricuspid valve annulus and one at the apex on the apical view of the RV, then the QLAB quantification software determined the boundary based on the selected landmarks, to build the 3D model. Aune’s method excluded the pulmonary valve resulting in an undesirable ellipsoid 3D shape output, which does not cover the trabecular nature of RV. Therefore, the volume was inaccurate. Earlier, Marwick *et al.* (2007) tracked the RV endocardial contours by semi-automatic border detection after determining the tricuspid annulus and apex for 12 long axis slices of the RV, a preconfigured ellipse was fitted into the endocardial boundary (which was used for left ventricle model) then applied on the ventricle wall with modification to fit the boundary with the endocardial border. Hoch *et al.* (2007) calculated the RV volume of RV latex model for the heart of lambs. The data was acquired using single wide-angle imaging. The volume measured by DSM using Tom Tec software <http://www.tomtec.de/on> a short-axis cutting plane. The gain was optimized to clearly visualize the endocardial rim. The disk thickness was 5mm and then the process was repeated for few times. At each time, they changed one of the three elements setting (disk orientation, gain, disk thickness). Then, the result of each setting was compared with the previous. This study concluded that RV volume measurement could be affected by the slicing direction, the slice thickness (number of disks) and the

gain. We should mention that this study did not include the outflow tract in the volume measurement.

Gopal *et al.* (2007; Horton *et al.*, 2009; Chua *et al.*, 2009), however, used Tom Tec system to measure the RV volume. 3D full-volume reconstructed surface from four wedges and RV boundary were determined manually to overcome the drop out of the inflow and outflow tract. Then 3D surface model was built using the method proposed by Weiss *et al.* (1982) for the Beulet 3D reconstructed surface. This method was used to reconstruct and measure the LV volume as well. Meanwhile, DSM method of 10 mm disk thickness with different width and length for each disk used as a second method by Gopal *et al.* (2007) in their study to compare the results with CMR technique. The boundary was determined manually at each plane. Wide angled full volume imaging from modified apical four-chamber view was used for imaging the RV cavity and DSM used to measure the stroke volume. This study has reported many limitations caused by the difference between the real anatomy and reconstructed surface. Such limitations are the imaging angle and the view caused a disappearance to the inflow and outflow tract and failed to determine the RV boundary accurately.

Sugeng *et al.* (2010) acquired RV from apical window using four consecutive gated cardiac cycle to reconstruct full-volume data. Manual initialization of contours was performed at one mid-ventricular short axis plane, apical four-chamber plan and coronal plan to create the 3D model. The ED and ES frames were determined manually. The volume was measured through the reconstructed surface model. This study concluded that the DSM obtained from 2D fundamental was inaccurate measurement method for RV volume. Earlier, Niemann *et al.* (2007) measured the RV volume from a full volume dataset. The RV cavity endocardial boundary determined through three views, the sagittal view plane to outline the tricuspid valve, four-chamber view used to outline the apex and a coronal view to outline the RV Outflow Tract (RVOT). The volume has been computed at the ED and ES frames by the summation of each slice area from a full volume dataset, including semi-automatic border detection with manual correction to build the 3D model. ED and ES frames were determined manually depending on the cine-loop images of the cardiac cycle; this measurement included 12 to 24 slices from the interventricular annulus to the ventricular outflow tract and excluded the interventricular septum and the apical component of the RV moderator band from the calculation.

In a comparison study of the RV volume measurement of using 3DE and MRI imaging, Crean *et al.* (2011) acquired RV from a modified four-chamber imaging view to maximize the visualization of RV. The volume

reconstruction was performed from 2D multiplanar view for semi-automatic intracardial boundary detection with manual correction. The ED and ES were selected manually by observing the individual image phases. Finally, the volume was measured based on the reconstructed 3D surface.

From the previously published literature concerning RV volume measurements, we noticed that most involved intensive manual interaction for RV contour detection. Likewise, those previous measurement methods adopted multi-view images in their approaches. This issue requires optimizing rotation angulation and manipulation to get the optimum view and enable boundary-tracing process. The 2D method fails to measure the RV volume because it is based on geometrical assumptions. However, many iterations were required to model a full structure of the RV. In addition, the Disk Summation (DS) approximation, which is an extension of a fundamentally 2D technique, fails to take full advantage of the RT3DE images that contain the entire ventricle, because of the failure of identifying the outflow tract accurately and include it in computing the volume of the RV cavity. Single wide-angle full-volume imaging of RV can cause disappearance of the inflow and outflow tract especially with dilated RVs.

6. 3D ILLUSTRATION OF RV ANATOMY

3D reconstruction is a vital approach in the medical field because it can provide more information leading to better analyses of human organs. The reconstruction models can be used to assist diagnostics and robotic surgery. However, the medical field is always open for challenges and there is always a material for research. There are different surface reconstruction methods presented for different data set type. In this section, the most frequent surface reconstruction methods used to reconstruct the 3D model of the heart ventricles from echocardiographic images are reviewed.

To the best of our knowledge, segmentation techniques used in medical imaging treat the extraction of the organ boundary as the most crucial step to assess and diagnose the organ status. Therefore, contour-based surface reconstruction techniques are widely used for medical images and give accurate results in organ surface reconstruction Qiang *et al.* (2007). In this technique, the cloud point data set \mathbb{R}^3 generated from the coordinates of the contour points of the extracted region from the slices are used in surface reconstruction. In the most frequent cases, either the input data set \mathbb{R}^3 requires pre-processing to generate accurate surface, or the reconstructed surface requires enhancement or post-

processing to satisfy the accuracy and fairness of the final shape. To reconstruct smooth surface from a set of parallel binary contours, (Braude *et al.*, 2007; Marker *et al.*, 2006) used the Multi-level Partition of Unity (MPU) approach to reconstruct an implicit surface for contour of large point set successfully. This approach focused on the local features and details even though it may show sampling/subdivision artifacts. Another approach was introduced by Qiang *et al.* (2007), where they developed the common known method Radial Based Function (RBF) interpolation to Localby adding forward and backward slices to keep the consistency of the surface. This technique was used for reconstructing surfaces from large datasets. Triangulation is also used to create meshes directly from the contours. This method is useful for convex contours only. Based on surface evaluation, Sahillioğlu and Yemez (2006) used surface deformation to produce a smooth and accurate surface. This technique overcomes the fold-overs and non-manifold triangulations problems. Miller *et al.* (1991), presented a deformable method to reconstruct close 3D surface of polygon, using a balloon model as a 'seed' model and deformed this balloon until it complies with the object surface (3D CT data used in this study). Cohen *et al.* (1992); Mcinerney and Terzopoulos, 1995) implemented an elastically deformable cylinder and sphere, respectively used finite element and physical-based techniques for anatomical based segmentation, reconstruction and tracking structures from multi-dimensional CT and MRI images. The surface consists of the triangular finite element model, which included position and first and second parametric partial derivatives of the surface. The model deformed to fit the data in an elegant and intuitive manner based on Lagrangian equations of motion, that adjust the model's deformational degrees of freedom to fit the LV data. This method worked successfully with multi-dimensional image slices that do not suffer from the banding artifacts.

7. DATA ORIENTATION

Point clouds by themselves are not useful to process the data and make measurements and other calculations. In addition, some data redundancy problems may exist in scanned data. This makes orienting unorganized cloud points crucial in surface reconstruction to get the correct connectivity for the sample points and identifying the inside/outside points. However, generating correct oriented vector in regions with very sparse points is a challenge.

Liu and Wang (2010) presented their Orienting approach (ORT) in the pre-processing step for surface reconstruction. This approach were performed through

three main steps, in the first step, a sphere splitting step based on eigenvalue analysis were added, to a modified scheme of generating adaptive spherical cover for unorganized points. Generated the triangular mesh surface and cleaned its topology, to find the closest triangle to every input points and then specify their orientations using a local search based algorithm, in the second step. Lastly, an orientation-aware principle component analysis step gives correct and consistently oriented normal vectors to the unorganized input points.

Adaptive Spherical Cover (ASC) was used to compute the oriented vector of the points nearest to the triangular mesh surface introduced earlier by Ohtake *et al.* (2005). Then, the oriented vectors are assigned to the unorganized points using Principle of Component Analysis (PCA). This technique doesn't modify the point cloud. Earlier, Amenta and Bern (1999) developed an algorithm for surface reconstruction of scattered and unorganized 3D data. The algorithm, which was based on a Voronoi diagram, guaranteed good results when a good sample of data was given. A good sample means capturing of intuitive notions to enable the areas with few samples.

8. CONCLUSION AND DISCUSSION

From the previous published literature concerning RV volume measurements, we noticed that measuring the RV volume still required intensive manual interaction for RV contour detection. Likewise, those previous measurement methods adopted multi-view images in their approaches. This issue requires optimizing rotation angulation and manipulation to get the optimum view and enable boundary-tracing process.

Disk Summation (DS) approximation, which is an extension of a fundamentally 2D technique, was one of the methods used to measure the RV volume. This method fails to take full advantage of the RT3DE images that contain the entire ventricle, because of the failure to identify the outflow tract accurately and include it in computing the volume of the RV cavity. Model-based measurement methods were also used by some researchers to measure the cavity volume from the 3D model that reconstructed from the cavity boundary. These methods however ignore the actual intracavity features and that leads to inaccurate results.

For segmentation, as shown in **Fig. 1**, different approaches were utilized. We can summarize it as boundary detection method with prior knowledge for ventricle feature regional segmentation method which used texture and watershed segmentation these methods extracted endocardial boundary, to reconstruct the 3D model.

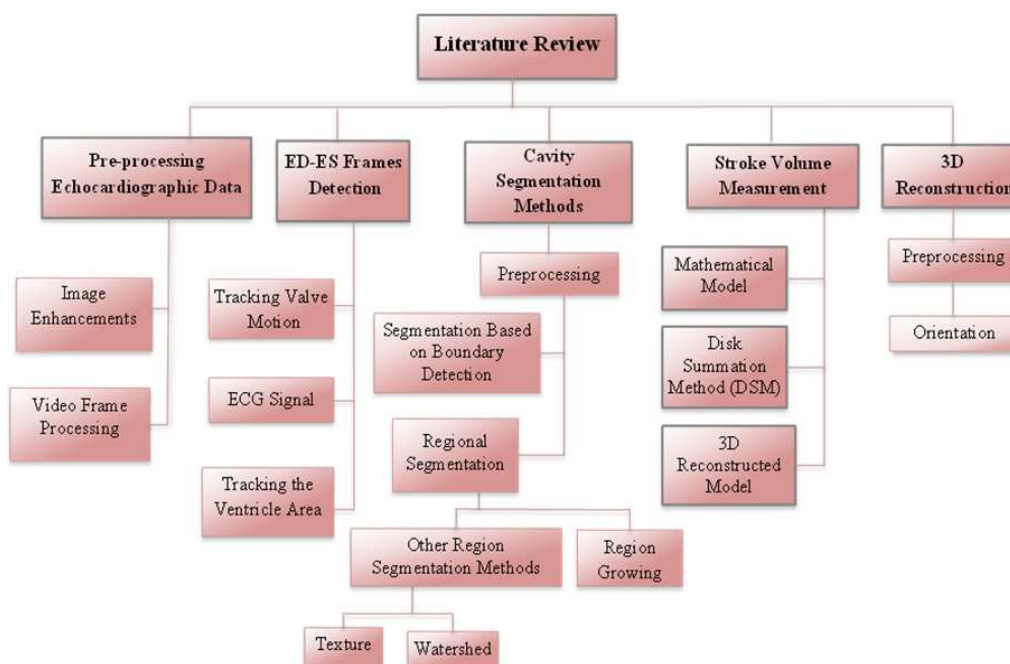


Fig. 1. Block diagram showing the reviewed approaches in this study

Meanwhile, the ED and ES frame detection is still done manually and depends on the user experience, which may effect on the accuracy of measurement results of the cavity stroke volume. Finally, the most frequent 3D reconstruction methods used with echocardiography images are reviewed.

It is obvious that there is a lack of concentration on the multifarious structure of the RV cavity (apex, moderator band, trabecular and inflow-outflow regions), in additional to the difficulty of identifying the endocardial boundary accurately in the End-Systolic stage of the RV due to more densely packed trabeculations and papillary muscles. Therefore, new algorithms are needed to assess the abnormality of the right ventricle. This process can be done by accurate segmentation of the cavity, determination of the End-Diastolic and End-Systolic stages of the cardiac cycle, measuring the stroke volume and reconstructing the three dimension model of the segmented region of the cavity for initial assessment of the abnormality.

Thus, we propose a method for semi-automatic segmentation of the right ventricle to measure the stroke volume from four Dimensions (4D) echocardiography, based on a novel analysing for the complex geometrical structure and function of the right ventricle, (Rahmat *et al.*, 2013; Anas *et al.*, 2014).

The right ventricle structure is simplified by slicing the right ventricle in 4D echocardiography images. Region growing technique is deployed to segment the cavity in each slice. This technique works automatically by detecting a seed point inside the Region of Interest (ROI), independently utilizing pre-knowledge of the region feature. Then start the iterative region growing segmentation process. Automatic detection for the End-Diastolic and End-Systolic stages of the cardiac cycle is introduced, by tracking the changes area of the segmented region of the cavity along one cardiac cycle. Disk summation principle is used to compute the volume of the segmented region in each slice. The resolution of the xMATREX array TEE transducer (X7-2t) is also estimated to measure the volume in milliliter unit. Then compute the cavity stroke volume by finding difference between the volume of the cavity at the ED and ES stages. The contours of the segmented region are extracted to generate the cloud of points (\mathbb{R}^3). Finally, generate three dimensions modelling for the segmented cavity by developing the normal feature approximation method for the cloud point, in order to accurately delineate the required object.

The proposed method requires minimal user-initialization to determine the ROI and executions, which requires only few seconds for one time along the processing time. Comparisons of the segmentation, end-

diastolic and end-systolic stages, stroke volume and the reconstructed 3D model; are provided with currently available software for left ventricle volume, function assessment and 3D modelling to validate the merit of the proposed work. The results of each step of process are satisfied high acceptance from the cardiologist experts in the qualitative validation and a good accuracy in quantitative validation regarding to techniques.

9. ACKNOWLEDGMENT

The researchers wish to thank the Heart and Lung Centre in PPUKM for providing us research time on the X-Ray imaging system, angiograms and echocardiograph images. We also thank all those lovely girls, Yan Yin Fong, Swee Lee Ping and Wei Bey Fenh for helping us implementing the system. This study was granted under Prototype Research Grant of Malaysia Minister of Higher Education with the title of "Visualization and Diagnostic of Coronary Arterial Stenosis through Voice Activation". This study was supported in part by Universiti Putra Malaysia, Faculty of Computer Science and Information Technology, Department of Multimedia under Fitting non-Uniform B-Spline Curve and Surface to Transesophageal Echocardiography Images to Determine and Abnormality of Cardiac Structure, FRGS, Project code:03-04-10-868FR, 24 months, April 2010-2012, RM44K grant.

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