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Towards Improving Cardiac Analysis Capabilities

Cardiovascular disease remains the leading cause of deaths in Europe. It is also the primary cause of disease burden on the healthcare sector. To reduce the mortality rate, it is vital to diagnose cardiac diseases early and follow up their treatment. Two-dimensional (2D) echocardiography is the frontline imaging modality for noninvasive cardiac functional analysis.

However, 2D echocardiography suffers from inherent shortcomings since it portrays a 2D representation of the complex shaped three-dimensional (3D) structures of the heart, which additionally has complex twisting motion. Therefore, functional analysis from 2D echocardiography is performed under geometrical assumptions, influencing its clinical value. Consequently, this brings significant subjectivity and variability to the analysis procedure. Real-time 3D echocardiography (RT3DE) is increasingly seen as an additional modality choice, since it captures the 3D shape and motion of the heart and offers improved accuracy and reproducibility for measuring important clinical parameters (e.g., volume and ejection fraction). However, the uptake of RT3DE in cardiology clinics has been slow, which can be attributed to two main factors. Firstly, often the images from RT3DE scanners suffer from lower quality, including lower temporal resolution, when compared to the state-of-the art 2D images. Moreover, RT3DE has limited field-of-view (FOV) and missing anatomical information.

Secondly, wider use of RT3DE is dependent upon the accurate and easy to perform delineation of the left ventricle (LV) boundaries. Automated LV delineation and tracking throughout the cardiac cycle from RT3DE is a nontrivial problem, while manual analysis is tedious, time-consuming and highly operator dependent. In summary, it is expected that improvements in RT3DE image quality and introduction of reliable and robust automated analysis methods will significantly influence much wider application of this very promising imaging modality in cardiology clinics worldwide.

Multi-view Fusion 3d Echocardiography

In this article, we present an overview of multi-view fusion 3D echocardiography as a solution to overcome the aforementioned limitations of RT3DE. Firstly, multiple RT3DE images having complementary information are acquired from different probe positions. Subsequently, these multiple RT3DE images are aligned and fused together in order to improve imaging of salient structures of the heart. The resultant image is defined as multi-view fused image, while each individual RT3DE image is called single view image. The multi-view fusion improves the image quality, increases anatomical information, and enlarges the captured field of view. In addition, it makes easier and more accurate automated analysis possible, because of the increased anatomical information in the image. This feature will potentially lead towards improving the capabilities of cardiac disease diagnosis.

How Does it Work?

An image acquisition protocol acquires multiple images of the heart from different trans thoracic apical view positions of the RT3DE probe. Particular care was exercised in designing this special protocol, such that the acquired multiple single view images have complementary anatomical information, while covering a wider FOV. The first image was acquired by placing the probe near the LV apex. More images were acquired by moving the probe laterally, medially, and one intercostal space above and below the first apical position. The probe movement was adjusted between multiple acquisitions by the sonographer to include all salient structures of the heart within wider FOV.

Due to freehand movement of the probe between multiple acquisitions, the multiple single view images differ between each other. However, the images have plenty of overlap owing to the small gap between probe positions. This overlap is used to determine the similarity between multiple single view images and transform them accordingly. Normalised cross correlation is used to measure the similarity between images. Keeping the first single view image (acquired from near the apex) fixed, other single view images are transformed for translation and rotation to bring them into correspondence with the fixed image.
Once the multiple images are aligned, the images are fused to blend together the complementary information from all the single view images. For this purpose, a method was developed that preserves the salient structures from each of the individual single view image. The method is based on a signal processing technique called the wavelet transform, which enables the decomposition of the image into signal and noise components that are then fused accordingly. The developed method is simple, efficient, fast, and has the ability to fuse any number of single view images. Figure 1 presents an example showing the multiple single view images and the result of multi-view fusion.

The results demonstrate that multi-view fusion brings considerable improvements in image quality and anatomical information present in the image. For the work in this article, full volume ECG gated RT3DE volumetric images were acquired from a Philips iE33 echocardiography scanner using X3-1 matrix array probe. In principle, this technique should also work on images acquired using matrix array probes from other vendor (e.g., GE, Siemens, and Toshiba).

Improving Anatomical Structure Information

The anatomical structure information is defined here as inner (endocardial) and outer (epicardial) boundaries of the myocardial muscle. This kind of structural information is vital for LV delineation (for the measurement of volume, ejection fraction, and cardiac mass) and LV tracking (for wall motion analysis). For each subject, the amount of structural information is computed for single view images and compared against the multi-view fused image. Studying a database of 36 volunteers, it was found that multi-view fusion 3D echo cardiography images preserve complementary salient structures from the single view images and have on average 12 percent more structural information compared to standard single view RT3DE images (Rajpoot et al., 2009a).

Improving Automated Analysis

To assess the completeness of anatomical information and its impact on automated analysis, a semi automatic imagedriven LV endocardial delineation algorithm was developed. For each subject, this algorithm was evaluated on single view and the multi-view fused image. For reference, an expert echocardiographer identified the endocardial borders in end-diastolic (ED) and end-systolic (ES) frames of each volume sequence. For each case the LV delineation algorithm was applied to the ED and ES frames of both the single view and the multi-view fused images. Successful convergence of the LV delineation method, to reach near the true LV endocardial border border delineated by experienced cardiologist), was observed and quantified (Rajpoot et al., 2009b).

For single view images, the LV delineation algorithm failed 88.2 percent of times at ED and 58.8 percent of times at ES. In comparison, for the multi-view fused images, the algorithm failed only 23.5 percent of times at ED and 2.9 percent of times at ES. Figure 2 shows an example LV delineation result on single view and multi-view fused images. e results indicate that the relatively fewer failures on multi-view fused images are an outcome of improvement in image quality and completeness of anatomical information.

Improving Image Quality

Single view and multi-view images were further assessed for completeness of anatomical information and for suitability to assess myocardial function (Szmigielski et al., 2009; Szmigielski et al., 2010). Two experienced echocardiographers selected the short-axis (SAX) and long axis (LAX) views from the 3D images and reviewed a total of 512 cardiac segments each for single view RT3DE and multi-view fused RT3DE images. Each segment was scored into one of the four categories: good quality, intermediate quality, poor quality, and out of sector. The results show that, due to multi-view fusion, the percentage point increase in good quality segments was 37.1 percent. The percentage point decrease in intermediate quality segments was 12.7 percent. The percentage point decrease in poor quality segments was 19.7 percent, while the percentage point decrease in out of sector segments was 4.7 percent.

Thus, the results show that fusion brings a considerable increase in the number of good quality segments and a notable decrease in the number of intermediate, poor quality, and out of sector segments. This demonstrates that multiview fusion improves complementary salient structures from the single view images.

Conclusions

Due to its ability to offer more accurate and complete cardiac analysis, multi-view fusion 3D echocardiography can play an important role in the future. Furthermore, this concept of multi-view fusion can certainly be useful in other areas such as stress 3D echocardiography, transoesophageal 3D echocardiography, and foetal 3D echocardiography.

Multi-view fusion 3D echocardiography results in a striking improvement in image quality. For clinical application, the current offline fusion process needs to be streamlined. In principle, it is possible to implement the fusion process into the echocardiography scanner and perform fusion in the background while scanning. It is very likely that multiview fusion will reduce false echocardiography diagnosis and provide better monitoring of heart disease. However, this needs to be proven in major clinical trials including stress echocardiography, contrast and 3D echocardiography. The trial studies will show how much better outcome can be achieved by the improved image quality and whether this is cost effective in comparison to other imaging modalities such as magnetic resonance imaging.

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