Temporal Super Resolution Enhancement of Echocardiographic Images Based on Sparse Representation

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***Abstract*—A challenging issue for echocardiographic image interpretation is the accurate analysis of small transient motions of myocardium and valves during real-time visualization. A higher frame rate video may reduce this difficulty, and temporal super resolution (TSR) is useful for illustrating the fast-moving structures. In this paper, we introduce a novel framework that optimizes TSR enhancement of echocardiographic images by utilizing temporal information and sparse representation. The goal of this method is to increase the frame rate of echocardiographic videos, and therefore enable more accurate analyses of moving structures. For the proposed method, we first derived temporal information by extracting intensity variation time curves (IVTCs) assessed for each pixel. We then designed both low-resolution and high-resolution overcomplete dictionaries based on prior knowledge of the temporal signals and a set of prespecified known functions. The IVTCs can then be described as linear combinations of a few prototype atoms in the low-resolution dictionary. We used the Bayesian compressive sensing (BCS) sparse recovery algorithm to find the sparse coefficients of the signals. We extracted the sparse coefficients and the corresponding active atoms in the low-resolution dictionary to construct new sparse coefficients corresponding to the high-resolution dictionary. Using the estimated atoms and the high-resolution dictionary, a new IVTC with more samples was constructed. Finally, by placing the new IVTC signals in the original IVTC positions, we were able to reconstruct the original echocardiography video with more frames. The proposed method does not require training of low-resolution and high-resolution dictionaries, nor does it require motion estimation; it does not blur fast-moving objects, and does not have blocking artifacts.**

***Index Terms*—Dictionary design, echocardiography, sparse representation, temporal super resolution (TSR).**

I. Introduction

ECHOCARDIOGRAPHY is one of the most widely used diagnostic tools for biomedical imaging in cardiology applications. This imaging modality—which provides real-time visualization of the function, size, and shape of the heart—is noninvasive, safe, and inexpensive.

It is essential to track the rapid motion/deformation of the myocardium and heart valves (such as the mitral valve apparatus, which includes the mitral valve, leaflets, subvalvular chordae, and papillary muscles) in real time to diagnose certain diseases, such as ischemia, mitral valve regurgitation, mitral and tricuspid valve prolapse, flail mitral and tricuspid valve, vegetation due to infective endocarditis, and left ventricular apical clots. Most common heart diseases can be better diagnosed using higher temporal resolution. Improving the methods for analyzing echocardiographic images of the myocardium and heart valves is therefore an essential topic in echocardiography research. Temporal super resolution (TSR) (i.e., high frame rate) is required to illustrate these fast-moving structures.

A real-time ultrasound image is constructed from several scan lines obtained in different directions in a very short period of time. The acquisition time (T_{fr}) for creating an image, which contains N_s scan lines, depends on the maximum imaging depth R and the speed of sound c. In ultrasound imaging, the speed of sound is the fundamental physical factor that limits the frame rate.

The frame rate ($f_{\mathrm{fr}} = \frac{1}{T_{\mathrm{fr}}} = \frac{c}{2RN_s}$) can be altered by varying the imaging depth and the number of scan lines. In ordinary echocardiography, the maximum frame rate is around 53 frames/s, considering 1500 m/s for the speed of sound, 11-cm imaging depth, and 128 lines per frame. However, this frame rate is not sufficient to analyze the fast-moving structures in fetal and small animal echocardiographic imaging as an example. Hence, a higher frame rate and full-view ultrasound imaging method is required [1], [2].

There are two sets of approaches to increase the frame rate in ultrasound imaging. The first one is based on acquisition schemes, while the second one is based on postprocessing techniques.

Previous literature details several methods for increasing the frame rate by using acquisition schemes. In [3] and [4], the frame rate was increased to 200 Hz by reducing the view angle and decreasing the number of lines in a sector. These methods are simple to use, but have limited application to echocardiography for two reasons. First, reducing the sector size prevents full-view cardiac imaging. Second, lateral resolution is decreased by lowering the line density.

Multiple line acquisition (MLA) [5], [6] and multiple line transmission (MLT) [7] are alternative ways to increase the

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