Postprocessing Approaches for the Improvement of Cardiac Ultrasound B-Mode Images: A Review

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***Abstract*—The improvement in the quality and diagnostic value of ultrasound images has been an ongoing research theme for the last three decades. Cardiac ultrasound suffers from a wide range of artifacts such as acoustic noise, shadowing, and enhancement. Most artifacts are a consequence of the interaction of the transmitted ultrasound signals with anatomic structures of the examined body. Structures such as bone, lungs (air), and fat have a direct limiting effect on the quality of the acquired images. Furthermore, physical phenomena such as speckle introduce a granular pattern on the imaged tissue structures that can sometimes obscure fine anatomic detail. Over the years, numerous studies have attempted to address a range of artifacts in medical ultrasound, including cardiac ultrasound B-mode images. This review provides extensive coverage of such attempts identifying their limitations as well as future research opportunities.**

***Index Terms*—Cardiac ultrasound, compounding, contrast enhancement, echocardiography, image enhancement, image filtering, noise suppression, review.**

I. Introduction

ECHOCARDIOGRAPHY provides a versatile, real-time diagnostic tool with no adverse secondary effects, capable of acquiring images of high spatial and temporal resolution at relatively low operational cost [1]. The wide range of available imaging techniques makes cardiac ultrasound a prevalent tool for the qualitative and quantitative assessment of cardiac morphology and function in both 2-D and 3-D. Cardiac ultrasound images can be acquired 1) through the thorax of the patient, also known as transthoracic echocardiography (TTE), or 2) from inside the esophagus of the patient (by utilizing specialized acquisition probes), also known as transesophageal echocardiography (TEE) [2]. TEE can generate high-quality images. However, the extended acquisition time and personnel requirements along with patient discomfort currently limit its clinical use, making TTE the common approach in clinical examinations. However, transthoracic cardiac ultrasound images are often incomplete (partial heart coverage) and suffer from a range of artifacts as a consequence of the interaction of the transmitted ultrasound signals with anatomic structures of the examined body. Structures such as bone, lungs (air), and fat have a direct limiting effect on the quality and diagnostic value of the acquired cardiac images. Furthermore, transthoracic cardiac ultrasound images a constantly and rapidly moving structure through the patient's rib cage. The nature of such a challenging acquisition enhances the manifestation of common medical ultrasound artifacts (Fig. 1).

Cardiac ultrasound images suffer from acoustic noise due to a range of acoustical phenomena (artifacts) such as reverberations, side-lobes, and grating-lobes [1], [2]. The extent of each artifact on the imaged cardiac structures depends on both the acquisition technology utilized as well as the echogenicity of the patient. For example, modern phased-array transducers minimize the effect of grating-lobes by using an adequately small pitch (less than half the wavelength of the transmitted signal) between the elements of the array. On the other hand, the effect of side-lobes, especially when transmitted in out-of-scan-plane directions, is mostly related to the proximity of extra-cardiac structures such as the lung and rib-cage bones. Furthermore, many instruments, especially phased array transducers, suffer from near-field clutter or ring-down effect [2]. Near-field clutter manifests itself at the top part of the scan as a zone with a high level of stationary noise that gradually declines to zero for increasing scanning depth [2]. Finally, oblique incidence angles of the transmitted ultrasound beam with respect to an imaged structure may result in low contrast between the cardiac tissue and chamber. A high-gain setting, possibly in an attempt to compensate for the low tissue signal, may result in additional amplifier noise mostly present in cardiac chambers. While not an exhaustive list, the aforementioned artifacts corrupt the imaged cardiac structures and from an imaging perspective can be considered as noise.

Imaging of relatively small and rapidly moving structures such as the cardiac valves introduces additional challenges. Besides the limited delineation as a result of noise, the structure may move into and out of the scan plane due to the cardiac and respiratory motion. Furthermore, reverberations and shadowing appear due to the interaction of the transmitted ultrasound with high reflective and attenuating structures, such as the patient's rib cage and lungs that lie in the path of the ultrasound beam. Such artifacts may appear momentarily or alter their position and orientation throughout a scan due to small movements of the transducer combined with the patient's respiration motion, obscuring the imaging of portions of the examined cardiac structure [1], [2].

Speckle is a type of acoustic phenomenon responsible for the granular appearance of ultrasound images. Speckle is a result of constructive and destructive interference of echoes produced by scattering of ultrasound at random, small-scale, tissue inhomogeneities. Speckle is a direct consequence of 1) the stochastic nature of the reflectivity of scattering media, and 2) the coherent