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● *Original Contribution*

NOVEL AUTOMATED MOTION COMPENSATION TECHNIQUE FOR PRODUCING CUMULATIVE MAXIMUM INTENSITY SUBHARMONIC IMAGES

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Abstract—The aim of this study was to develop a novel automated motion compensation algorithm for producing cumulative maximum intensity (CMI) images from subharmonic imaging (SHI) of breast lesions. SHI is a nonlinear contrast-specific ultrasound imaging technique in which pulses are received at half the frequency of the transmitted pulses. A Logiq 9 scanner (GE Healthcare, Milwaukee, WI, USA) was modified to operate in gray-scale SHI mode (transmitting/receiving at 4.4/2.2 MHz) and used to scan 14 women with 16 breast lesions. Manual CMI images were reconstructed by temporal maximum-intensity projection of pixels traced from the first frame to the last. In the new automated technique, the user selects a kernel in the first frame and the algorithm then uses the sum of absolute difference (SAD) technique to identify motion-induced displacements in the remaining frames. A reliability parameter was used to estimate the accuracy of the motion tracking based on the ratio of the minimum SAD to the average SAD. Two thresholds (the mean and 85% of the mean reliability parameter) were used to eliminate images plagued by excessive motion and/or noise. The automated algorithm was compared with the manual technique for computational time, correction of motion artifacts, removal of noisy frames and quality of the final image. The automated algorithm compensated for motion artifacts and noisy frames. The computational time was 2 min compared with 60–90 minutes for the manual method. The quality of the motion-compensated CMI-SHI images generated by the automated technique was comparable to the manual method and provided a snapshot of the microvasculature showing interconnections between vessels, which was less evident in the original data. In conclusion, an automated algorithm for producing CMI-SHI images has been developed. It eliminates the need for manual processing and yields reproducible images, thereby increasing the throughput and efficiency of reconstructing CMI-SHI images. The usefulness of this algorithm can be further extended to other imaging modalities. (E-mail: flemming.forsberg@jefferson.edu) © 2009 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Subharmonic imaging, Cumulative maximum intensity, Sum of absolute difference technique, Motion compensation, Breast imaging, Image processing.**

INTRODUCTION

Breast cancer is the second-most common form of cancer in women (U.S. Cancer Statistics Working Group 2007). Mammography is the method of choice for both screening and diagnosing breast cancer; although the vast majority of breast biopsies performed in clinical practice (between 65% and 90%) are found to be benign when assessed histopathologically (Kopans 1998; Tabar and Dean 2003; Zonderland et al. 1999).

Alternatively, recent advancements in nonlinear ultrasound (US) scanning using contrast agents have been shown to increase the specificity and sensitivity of diagnostic US imaging (Ferrara et al. 2000; Frinking et al. 2000; Goldberg et al. 2001). Doppler examinations using contrast agents have not only improved visualization of deep and small vessels with low or slow flow, but have also enhanced detection of flow within abnormal vessels because of the enhancement of the backscattered signal by the microbubbles (Correas et al. 2001). However, in conventional Doppler imaging modalities the microbubbles are analogous to conventional tissue scatterers. Instead, the nonlinear interaction between microbubbles and the US beam can be exploited to improve microbubble detection.

Harmonic imaging (HI) is one such nonlinear contrast-enhanced US imaging modality (Correras et al

Video Clips cited in this article can be found online at: http://www.umbjournal.org.

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2001; Goldberg et al. 2001). In HI, the US beam is transmitted at a fundamental frequency f_o and the displayed image is reconstructed from the second harmonic component $2f_o$. One of the major disadvantages of HI is that the tissue also produces sufficient harmonic energy to be detected by the high sensitivity and bandwidth of modern US equipment (Frinking et al. 2000; Goldberg e al. 2001). Furthermore, the higher attenuation of the harmonic frequencies compared with the fundamental frequency reduces imaging depth (Correas et al. 2001).

Microbubbles not only enhance the backscattered signal but also create significant subharmonic components of the incident ultrasonic waves. These subharmonic emissions may be used for nonlinear contrast-specific subharmonic imaging (SHI), wherein the signal is transmitted at one frequency, f_0 and the echoes are received at half the frequency, $f_0/2$ (Forsberg et al. 2000, 2007; Shi et al. 1999). The lack of subharmonic generation in tissue and significant subharmonic scattering produced by contrast microbubbles may be useful to distinguish between tissues and vascular structures (Forsberg et al. 2000). Furthermore, SHI may also be suitable for scanning deep-lying structures, owing to much smaller attenuation for backscattered subharmonic signals relative to higher harmonic signals (Shi et al. 2001). Importantly, Shankar and colleagues (1998) showed that the ratio of subharmonic signal obtained from contrast agent in the blood to that obtained from the surrounding tissue is greater (by about a factor of 10) than the ratio of second harmonic signal obtained from contrast in blood and that obtained from the surrounding tissue. Thus, the higher backscattered subharmonic signal from the contrast agents compared with the second harmonic signal motivates the use of SHI to visualize tumor neovascularity. The administered contrast will trace the vasculature in the breast, which is indicative of the blood flow to nourish the cells, both normal as well as cancerous (Weidner et al. 1992). Because angiogenic vascular morphology is an independent predictor of malignant breast diseases, it is an important marker for breast US flow imaging (Gasparini and Harris 1995; Relf et al. 1997).

Forsberg and colleagues (2007) have shown that SHI may improve the diagnosis of breast cancer relative to conventional US and mammography. This group further demonstrated that the area under the receiver operator characteristics curve for SHI was greater than that of contrast-enhanced power Doppler US (0.76 *vs.* 0.67), suggesting that SHI may have a potential to improve the diagnosis of breast cancer. To improve visualization of the microvasculature in contrast-enhanced breast SHI, this group also proposed using manually reconstructed, static cumulative maximum intensity (CMI)-SHI images (Forsberg et al. 2006).

The CMI imaging mode is akin to established commercial replenishment techniques, such as MicroFlow Imaging (Toshiba America Medical Systems, Tustin, CA, USA) and MicroVascular Imaging (Philips Medical Systems, Bothell, WA, USA), where a composite image producing a snapshot of embedded vascularity is constructed through maximum-intensity capture of imaging data over consecutive images after a high-transmission power US exposure to destroy contrast bubbles within the imaging plane (Averkiou et al. 2003; Forsberg et al. 2006; Sugimoto et al. 2008; Wilson et al. 2008; Yang et al. 2007). This is achieved using the maximum-intensity projection (MIP) algorithm (Hyde et al. 2007), which performs one-to-one mapping of the maximum-intensity pixels from corresponding locations in all the frames onto the final reconstructed image as shown in Fig. 1. The

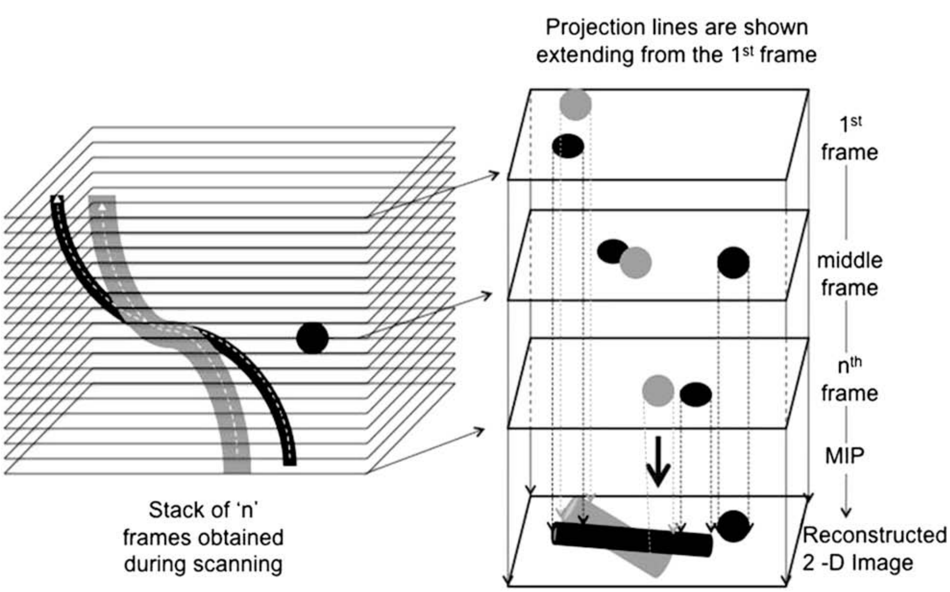

Fig. 1. Schematic of MIP algorithm to produce maximum-intensity image.