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Principle-Component-Analysis Based Motion Magnification for B-mode Visualization of Magnetomotive Ultrasound

Wei-Hsiang Shen
Department of Electrical Engineering
National Tsing-Hua Univeristy
Hsinchu, Taiwan

Meng-Lin Li
Department of Electrical Engineering and
Institue of Photonics Technologies
National Tsing-Hua Univeristy
Hsinchu, Taiwan
mlli@ee.nthu.edu.tw

***Abstract*—Magnetomotive ultrasound (MMUS) is an emerging technique to image super-paramagnetic iron oxide nanoparticles (SPIOs) in tissues. An oscillating external magnetic field is applied to induce magnetomotion of the SPIOs, and then sub-wavelength motion tracking is performed to track motion sources for the mapping of the SPIO distribution because generally such magnetomotion is too small to be visible directly in conventional B-mode imaging. Our previous work attempted to use frequency-based filters to perform motion magnification and visualize motion patterns from the SPIOs in B-mode imaging. However, in many MMUS applications, the frequencies of the magnetomotion signals from the SPIOs and motion noises are overlapped, and thus the two cannot be separated simply by frequency-based filters, resulting in poor performance of motion magnification. To solve this problem, we propose a novel principle-component-analysis (PCA) based motion magnification method for direct B-mode visualization of SPIO magnetomotion in MMUS. The proposed method can reveal originally invisible sub-wavelength magnetomotion in B-mode images without the need of sub-wavelength motion tracking. PCA-based filtering with different order selection and eigen-space weighting enables the extraction and magnification of the target motions which are previously non-separable from motion noises by using frequency-based filters. MMUS simulation and experimental results (not shown here) show that it is easy to localize the magnetomotion sources, i.e., the SPIOs, and visualize the shear wave propagation induced by magnetic excitation in B-mode images even when the magnetomotion is corrupted by the frequency non-separable tissue motion. Overall, the PCA-based motion magnification technique offers a more generalized B-mode representation of the originally invisible magnetomotion and magnetic-excitation-induced shear wave propagation, waiving the need of sub-wavelength motion tracking.**

Keywords—principle component analysis, motion magnification, magnetomotive ultrasound

I. INTRODUCTION

Recently, nanoparticles have been used as contrast agents in ultrasound imaging to perform molecular imaging. Oh et al. [1] proposed magnetomotive ultrasound imaging (MMUS) and used it to detect magnetic nanoparticles. An external oscillating magnetic field is used to induce motion on magnetic nanoparticles within the tissue; then the induced motion can be tracked using ultrasound signals and then magnetic nanoparticles can be localized.

Since the induced magnetomotion and its shear wave propagation is on the scale of sub-micrometer to few-micrometer, it is invisible in conventional B-mode imaging. Computation-heavy algorithm has to be used to track the vibration of nanoparticles [2][3]. Yeh et al. [4] proposed the B-mode subwavelength vibration imaging and used it to magnify and visualize the induced vibration of nanoparticles and the induced shear wave propagation of MMUS. the B-mode subwavelength vibration imaging creates visualization directly on B-mode images, and waives the need of computation-heavy tracking algorithms.

However, such approach has two main problems. First, it assumes that the target motion is small enough, so that larger motion creates unreal magnified motion. Second, when the frequencies of magnetomotion from the magnetic nanoparticles and motion noises are overlapped, frequency-selective filters used in the algorithm cannot easily extract the desired magnetomotion which causes motion magnification to fail completely. Especially, this is the case encountered in *in vivo* data where the noises are larger and more complex.

Principle component analysis (PCA) based signal separation showed great results of separating tissue signals and blood signals in ultrasound imaging [5][6]. Inspired by such work, in this paper, we propose a new PCA based motion magnification technique for ultrasound B-mode imaging that uses PCA to separate the target magnetomotion and undesired motion noises. The proposed PCA-based motion magnification method is validated on simulation, phantom and *in vivo* data (phantom and *in vivo* results are not shown in this paper), and compared against the previously proposed B-mode subwavelength vibration imaging, showing significant improvement in visualization quality of magnified motion in B-mode imaging,

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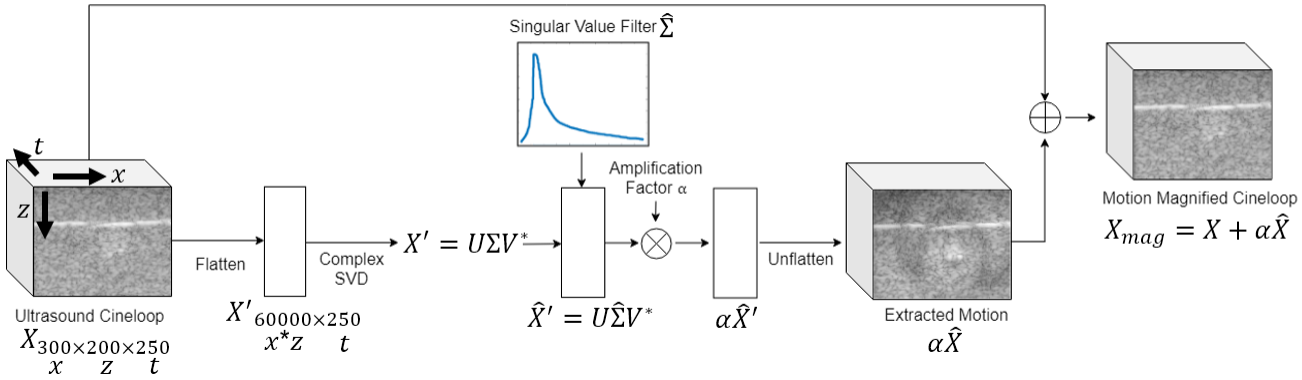

Fig. 1. Overview of the PCA-based motion magnification framework.

II. Materials and Methods

A. PCA-Based Motion Magnification

Motion magnification is to enlarge the originally invisible motion so that we can observe it directly in B-mode imaging. In the case of MMUS, motion magnification is performed on beamformed B-mode baseband frames so the result would be B-mode frames with magnified motion that can be directly viewed.

Our approach uses a singular value filter to extract the target magnetomotion, and an amplification factor α to control the level of magnification. The framework is illustrated in Fig 1. Consider an ultrasound cine loop data with 300 pixels in lateral, 200 pixels in axial, and 250 frames. This 3D data matrix can be flatten into a 2D matrix by flattening the two spatial axes.

$$X_{300\times200\times250} \rightarrow X'_{60000\times250} \quad (1)$$

In the perspective of singular value decomposition (SVD), this is treated as 250 observation, each with 60000 features. By doing so, SVD can simultaneously access both spatial and temporal information. Then, complex SVD is performed on the 2D data matrix, where U is the left singular vector, Σ is the singular value matrix, V is the right singular vector.

$$X' = U\Sigma V^* \quad (2)$$

Then, by using a custom-designed singular value filter $\hat{\Sigma}$, we can extract the target motion signal.

$$\hat{X}' = U\hat{\Sigma}V^* \quad (3)$$

The extracted motion is then multiplied by an amplification factor α to control the level of magnification. The 2D matrix $\alpha\hat{X}'$ is then unflatten to a 3D matrix $\alpha\hat{X}$ and the axial and lateral axes are recovered. The extracted, magnified motion $\alpha\hat{X}$ is added back to original 3D data to form the motion-magnified B-mode frames.

$$X_{mag} = X + \alpha\hat{X} \quad (4)$$

In this framework, SVD serves as a method of signal separation to extract the target motion, and the amplification factor implicitly magnifies the extracted motion. When using an amplification factor α, the target motion is magnified α+1 times.

B. Design of Singular Value Filter

SVD is an adaptive and data-driven decomposition method, so it is difficult to predict the result in advance. When examine the decomposed singular vectors, as shown in Fig 2, we can see that the latter singular vectors which have smaller singular values are mostly noises. This is a standard outcome of any PCA-based decomposition, since PCA projects the data into a different coordinates according to their correlation, so that the latter vectors have little contribution to the data.

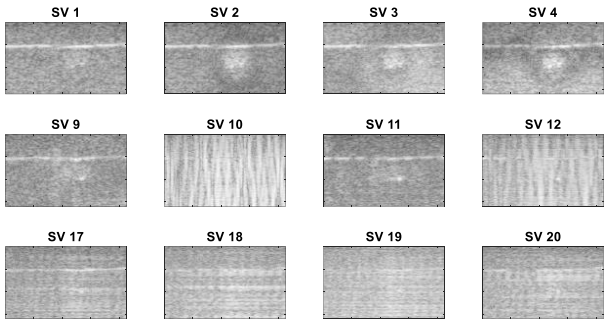

Fig. 2. Visualization of the decomposed singular vectors; vectors 21 to 250 are omitted. Latter vectors are mostly noise-like patterns, while the earlier vectors present different view points of the original data.

Also, the design of singular value filter should resist the first few vectors since they contribute to the static tissue and structure, not the motion. Different MMUS systems should have different characteristic of the SVD result. By experiment, we found that in our MMUS system, the first 3% to 6% vectors contribute mostly to the magnetomotion.

III. Results

Simulations were performed using the Field II [7] toolbox. The phantom has a vibration source in the middle and the vibration source induces shear wave to propagate. This was to

simulate the phenomenon when magnetic particles are excited by an external magnetic field. In addition, a left and right periodic motion was added to the vibration source to simulate the motion noises (e.g. heart rate, respiratory motion) we might encounter in *in vivo* data.

We performed the previously proposed B-mode subwavelength vibration imaging and our PCA-based motion magnification to visualize the magnetomotion, as shown in Fig 3. Without motion magnification, we could not see any change in the B-mode frames nor any shear wave propagation (first row). B-mode subwavelength vibration created unreal magnified motion and it resulted in two vibration sources and failed to give an accurate magnification result (second row). PCA-based motion magnification could magnify the previously invisible motion, while preserving the left to right motion of the vibration source and the induced shear wave propagation (third row).

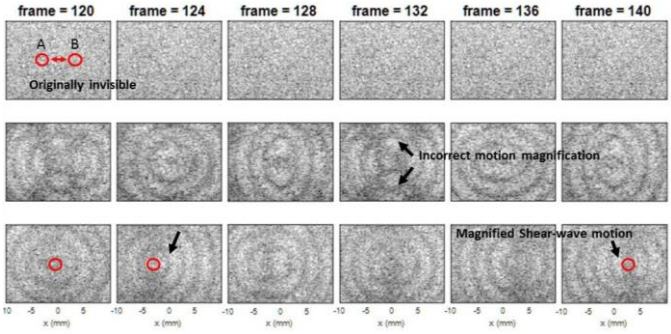

Fig. 3. Result of motion magnfication. The first row is the original B-mode frames; the second row is the result with our previously proposed B-mode subwavelength vibration imaging; the third row is the result of our PCA-based motion magnification.

IV. Conclusion

In this work, we propose a new PCA-based motion magnification technique for visualizing magentomotion in MMUS and it shows better performances than the previously proposed method. It is easier to see the vibration source and the induced shear wave propagation. Our approach was also validated on phantom and *in vivo* data, and showed good magnification results similar to the simulation ones (Note that these data are not shown here). Overall, PCA-based motion magnification offers a more generalized B-mode representation of the originally invisible motion and waives the need of subwavelength motion tracking.

This work is also expected to benefit the studying of motion patterns from the magnetic nanoparticles. In addition to magentomotion visualization, we believe that the proposed visualization technique also owns great potential in B-mode visualization of radiation force induced shear wave propagation.

Acknowledgments

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