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Revolving permanent magnet causes rotating particle motion that makes new detection schemes possible in magnetomotive ultrasound

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***Abstract*—Magnetomotive ultrasound, MMUS, can reveal the presence of a magnetic contrast agent by applying an external magnetic field. If the interaction between the agent and the field is strong enough, a movement that can be detected by ultrasound is induced in the surrounding tissue, thereby inferring the contrast agent distribution. Electromagnets have been used to generate the necessary magnetic field, but due to their size, weight, and propensity to heat up, they are impractical to work with. Furthermore, the resulting magnetic force is directed mainly along the symmetry axis of such magnets, and thus the resulting movement is primarily a one-dimensional oscillation. We suggest the use of a rotating permanent magnet that generates a two-dimensional particle motion, and that this makes new detection schemes for MMUS possible. A prototype probe, containing a rotating neodymium magnet, was used to move a metallic sphere embedded in tissue-mimicking material. Cine loops recorded any in-plane movement with the magnetic probe placed in two different positions. A two-dimensional movement was demonstrated, using both our previously developed MMUS algorithm as well as a phase-based motion tracking algorithm. The conventional 1D MMUS processing detected the axial component in both magnetic probe positions, whereas the two-dimensional motion tracking algorithm estimated a rotational motion from the same measurements. The added dimension of motion could engender possibilities to more precise signal processing and thus improve robustness of magnetomotive motion detection. Moreover, the incorporation of a permanent magnet makes for a more practical device, as compared to using electromagnets.**

Keywords— Magnetomotive, 2D, motion tracking, rotating, permanent

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I. Introduction

In magnetomotive ultrasound (MMUS), a time-varying external magnetic field is used to displace magnetic nanoparticles, with simultaneous ultrasound detection of the resulting motion [1]. The most commonly used magnetic field generators in MMUS are electromagnets. In order to produce a strong magnetic field, they tend to heat up and are usually large in size and therefore difficult to handle. To address these problems, we recently presented a prototype for a handheld magnetic probe with a rotating permanent neodymium magnet, generating a sinusoidally time-varying magnetic field [2]. This probe does not generate heat, and is smaller in size, which would facilitate its use in a clinical setting, but it comes with the drawback of shorter magnetic force range as compared to larger electromagnets.

For a traditional MMUS setup with an electromagnet, the magnetic force created is almost exclusively acting in the axial direction, resulting in an essentially purely axial magnetic particle motion. In the case of a rotating magnet, the induced magnetic particle motion is expected to be different; as the magnet rotates, magnetic particles in its vicinity will experience a rotating force. During one full revolution, the magnetic force vector in a point outside of the magnet is caused to rotate twice. This is due to the fact that a paramagnetic particle is attracted to both poles of the magnet

A two-dimensional rotational motion can be useful for devising novel detection schemes. In-plane rotation would appear as an oscillation in one dimension, which is still detectable with axial motion tracking. However, having access to the full motion in 2D could be exploited to increase specificity. The aim of this study was to confirm a rotational movement with MMUS. This will be done by using both our previously developed MMUS algorithm [3] and also with a phase-based motion-tracking method [4]. The first one detects axial movement only, whereas the latter also detects movement in the vertical direction.

II. Method

A. Styrene-Ethylene/Butylene-Styrene (SEBS) Phantom

The gel was prepared by mixing 8% Styrene-Ethylene/Butylene-Styrene (SEBS) (Kraton Polymers) with paraffin oil (TRIKEM VET, Malmö, Sweden) in a beaker. The mixture was placed in an oven (Nüve, Ankara, Turkey) at 130 degrees centigrade until the powder had completely dissolved. 30 mg graphite (Merck GKaA, Darmstadt, Germany) per milliliter solution was added to act as an ultrasound scatterer. A 2×2 cm brass mold was then half-filled and returned to the oven to ensure any air bubbles would rise to the surface. The mold was then left to solidify at room temperature before the stainless steel sphere was placed at the center and covered with liquid SEBS mixture.

B. Experimental setup

The phantom was imaged using a 35 MHz transducer with a Visualsonics Vevo 2100. The phantom was positioned on top of the transducer and kept in place using adhesive tape. The magnetic probe was positioned with the rotational axis orthogonal to the image plane, either such that the center of the transducer, sphere and probe were aligned, or with the probe to one side of the phantom (position A and B in Fig 1).

Cine loops (200 frames at 100 frames per second) were obtained with the magnetic probe at four different distances from the metal sphere, ranging from 9.8 mm to 26.5 mm. The magnet rotated at 120 rpm, inducing a 4 Hz movement of the sphere.

C. Signal Processing

To analyze the movement, both our previously developed MMUS algorithm [3], and a phase-based motion tracking

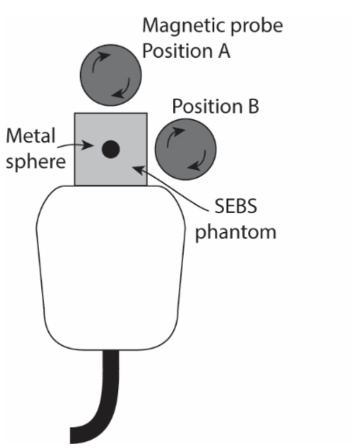

Fig. 1. Phantom positioned on ultrasound transducer. The two magnetic probe positions (A and B) are also illustrated. When the distance between probe and sphere are equal for A and B, the magnetic force should be the same in both cases.

method, [4] were used. The former method tracks motion only axially, using the phase variation of the IQ-data between frames [3], while the second computes the movement using spatial phase information derived from amplitude data, and can be generalized to capture motion also laterally [4]. A rotational particle movement was expected in both magnetic probe positions, with decreasing amplitude of movement as separation increases, due to the distance dependency of the magnetic force.

III. Results

Fig. 2 shows resulting average displacements over an area containing the sphere, identified in the B-mode image, detected using our MMUS algorithm for the two magnetic probe configurations A (red) and B (blue) respectively.

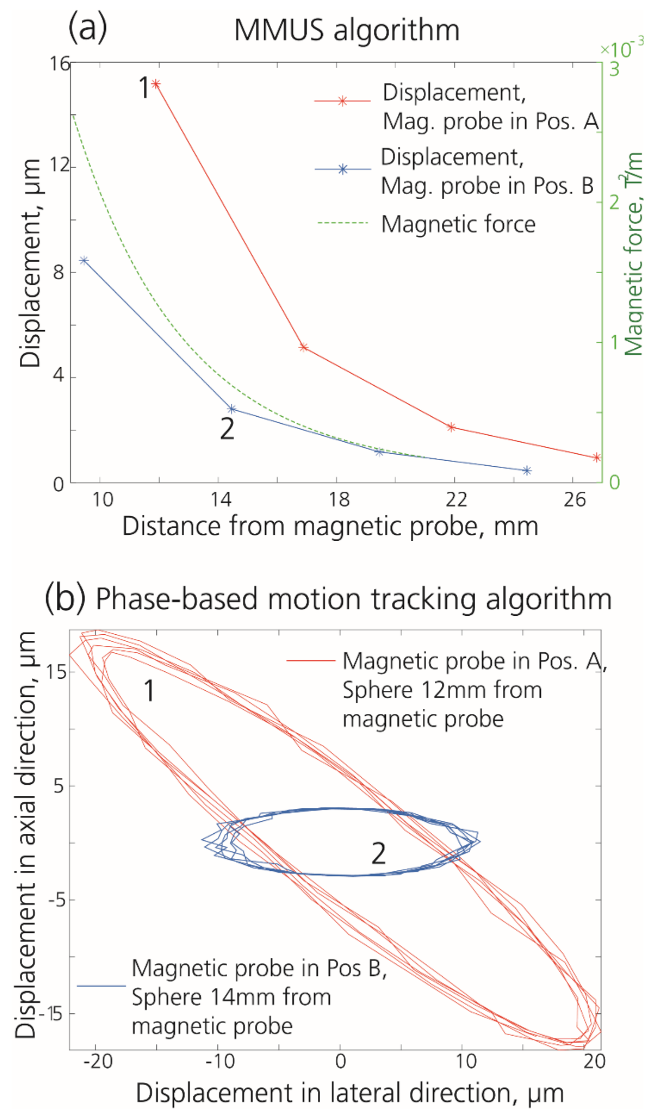

Fig. 2. (a) Axial magnetic displacement calculated by the first algorithm with the magnetic probe aligned with the ultrasound transducer (position A), parallel to the center line, at the level of the metal sphere (position B). A proxy for the magnetic force, the field times its spatial gradient along the radial direction of the magnetic probe, was calculated from field measurements. This has been included as a function of distance. (b) In plane rotational motion estimated using phase-based tracking, with magnetic probe in position A, at a distance of 12 mm, and in position B, at 14 mm.

From Fig. 1a it is apparent that the movement has two perpendicular components, because a movement of similar size was detected with the magnetic probe in either orientation relative to the ultrasound transducer. Fig. 2b shows the movement in a region of interest corresponding to the location of the sphere during 1.5 s using the phase-based algorithm. 1 and 2 in Fig. 2b refer to the corresponding measurements as shown in Fig. 2a. The phase-based algorithm confirms an elliptic rotational motion that is slightly smaller in the axial direction, independent of magnetic probe position. Both algorithms produce a larger movement when the magnetic probe is aligned with the ultrasound propagation direction.

IV. Discussion and Conclusions

The findings support that the metal sphere undergoes a rotational motion in the presence of a rotating magnet. For the MMUS algorithm, an axial motion was detected with the magnetic probe in both positions, which shows that there are two perpendicular components to the magnetic force in this case, with one extending out radially and another in the tangential direction to the cylindrical magnetic probe. The two-dimensional motion tracking algorithm shows that the motion is indeed describing an ellipse in the image plane, as it takes both of these components into account simultaneously.

Fig 2b also indicates that the axial motion is smaller than the lateral. We presume this is due to the restriction in this direction due to the transducer interface and the adhesive tape.

Motion estimates differed between the two processing methods, with the 1D MMUS approach generally producing the lower estimate for peak to peak motion. This might be in part due to that averaging over a larger region is taking place in this case, while the results of the 2D method are calculated for a smaller region of interest. Irrespective of this discrepancy, both methods do indicate a two-dimensional motion, with similar amplitude for the two components.

While providing a lighter, smaller, and heating free magnetic excitation probe, the rotating permanent magnet might also open paths to novel detection schemes. Considering both components of the induced movement together could, for example, increase the robustness against movement artifacts and enable detection of smaller magnetomotion.

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References

[1] Oh, Junghwan, Feldman, Marc D, Kim, Jeehyun, Condit, Chris, Emelianov, Stanislav & Milner, Thomas E. “Detection of Magnetic Nanoparticles in Tissue Using Magneto-Motive Ultrasound.” Nanotechnology, vol. 17, no. 16, Aug. 2006, pp. 4183–4190.

[2] Sjöstrand, Sandra, Evertsson, Maria, Lindquist, Ulrika, Lindkvist, Rebecka, Andresson, Roger, Wahlström, Anders, Nybom, Göran, Svensson, Ingrid, Cinthio, Magnus, Jansson, Tomas, "Revolving Permanent Magnet for Magnetomotive Ultrasound". 2018 IEEE International Ultrasonics Symposium, IUS 2018. IEEE Computer Society. 2018.

[3] Evertsson, Maria, Cinthio, Magnus, Fredriksson, Sarah, Olsson, Fredrik, Persson, Hans W, Jansson, Tomas, “Frequency- and Phase-Sensitive Magnetomotive Ultrasound Imaging of Superparamagnetic Iron Oxide Nanoparticles.” IEEE Transactions On Ultrasonics Ferroelectrics And Frequency Control, no. 3, 2013, p. 481.

[4] Nilsson, Tobias, Rydén Ahlgren, Åsa, Albinsson, John, Segstedt, Simon, Nilsson, Jan, Jansson, Tomas, Persson, Hans W & Cinthio, Magnus 2013, “A fast 2D tissue motion estimator based on the phase of the intensity enables visualization of the propagation of the longitudinal movement in the carotid artery wall.” 2013 IEEE International Ultrasonics Symposium, IUS 2013. IEEE--Institute of Electrical and Electronics Engineers Inc., pp. 1761-1764.