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# Real-time and high-resolution magnetic particle optical imaging

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**Abstract**

Magnetic nanoparticles (MNPs) have emerged as a promising medical imaging contrast agent due to their non-toxic and non-invasive properties, among others. This suggests that they possess significant potential for future applications. However, when it comes to imaging dynamic and rapid physiological processes, real-time visualization becomes crucial. In order to address this challenge, we propose a magnetic particle optical imaging (MPOI) approach that enables real-time imaging of MNPs under the influence of an external magnetic field. Our experimental results demonstrate that MPOI can achieve a frame rate of 20 frames per second (FPS), allowing for the accurate tracking of the movement of a copper wire within an MNPs suspension. This finding highlights the spatial resolution and real-time performance advantages of the MPOI method. Consequently, this method opens up exciting possibilities for the real-time imaging of various rapid physiological activities in the future.

## I. Introduction

Magnetic particle imaging (MPI) has great potential as a non-ionizing radiation imaging technique for contrast imaging of blood vessels or various organs [1–3]. However, the spatial localization of traditional imaging methods is achieved by scanning free-field points (FFP) or free-field lines (FFL) in space, resulting in a scanning time of approximately 1 second for the entire field-of-view (FOV) [4]. This makes it unlikely to capture and track dynamic and fast physiological processes, such as blood flow and heartbeat, in real-time [5]. Additionally, the reconstructed images only contain signals generated by the MNPs and lack structural imaging of the organism itself [6]. Therefore, traditional MPI methods do not accurately localize relative spatial positions.

Our recently proposed magnetic particle optical imaging (MPOI) method can utilize the modulation of transmitted light intensity by MNPs under the excitation of an external magnetic field to achieve imaging of MNPs with a spatial resolution of 10 µm [6]. Compared to conventional MPI, optical imaging has the advantage of being fast and capable of achieving precise localization in vivo without the aid of CT imaging, although the depth of light penetration is currently limited in vivo.

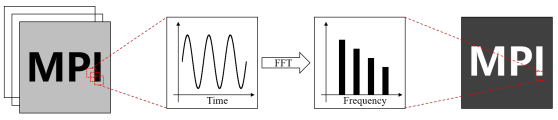


**Figure 1:** Schematic diagram of the magnetic particle optical imaging method

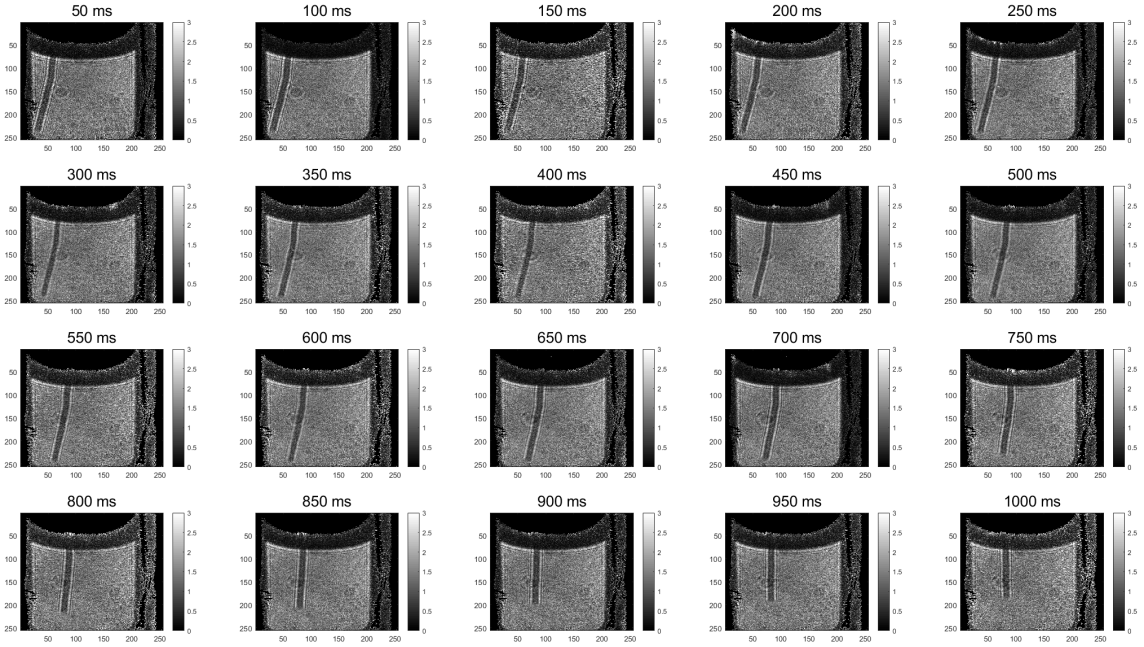


**Figure 2:** The reconstructed images of the MNPs distribution where grayscale represents the concentration of MNPs, the total sampling time is 1s and each frame is 50 ms.

## II. Principle and method

The experimental setup begins by illuminating the MNP samples in the cuvette with uniformly distributed monochromatic light. Subsequently, the MNPs are modulated by sinusoidal AC magnetic field excitation. Finally, a high-speed camera is used to collect the light intensity transmitted through the MNP samples [7]. The schematic diagram of the signal processing is shown in Figure 1. The light intensity of each pixel point on every frame is rearranged into a time-domain signal, which is then subjected to fast Fourier transformation to obtain a frequency-domain signal. The octave harmonic signal corresponding to the excitation magnetic field frequency is extracted. Since the change in transmittance caused by the magnetic field excitation results in the harmonic amplitude containing information about the concentration of MNPs [8], the distribution of MNPs can be obtained through image reconstruction using the harmonics from different pixels.

The gray scale values in each frame of the original photograph captured by the camera represent the light absorption by different substances, similar to Computed Tomography (CT) imaging. Thus, the original photographs obtained through this method can provide information about the surrounding structures in addition to the MNPs. In the MNPs distribution image obtained after performing image reconstruction, the gray scale values indicate the concentration of MNPs. Therefore, the reconstructed image specifically reflects the concentration of MNPs, while the rest of the structure is not relevant. In the accompanying experimental results, it can be observed that, apart from the MNPs appearing as white, other components are displayed as black.

## III. Result and discussion

The experimental materials included a 1 mL sample of MNPs and a copper wire (which is not influenced by the magnetic field), both of which were placed in a cuvette. During image reconstruction using harmonic amplitude, only the MNPs are relevant, while other components do not affect the results. Consequently, the movement of the copper wire within the MNPs suspension can be observed. The data acquisition duration for the entire experiment was 1 second. Image reconstruction was performed on the collected data at 50 ms intervals during processing, as illustrated in Figure 1, resulting in the generation of 20 reconstructed images.

The results, depicted in Figure 2, demonstrate that the MNPs and copper wire in the reconstructed image with a 50 ms interval can be distinctly differentiated. Additionally, the positional variations of the copper wire over time are clearly recorded. We documented the coordinates of the endpoints of the copper wire and plotted them, as illustrated in Figure 3. It is evident from the plot that the movement of the copper wire in the upper-right direction is visually captured within a 1-second timeframe.

The portion of the reconstructed image where the copper wires and the vessel wall appear gray instead of

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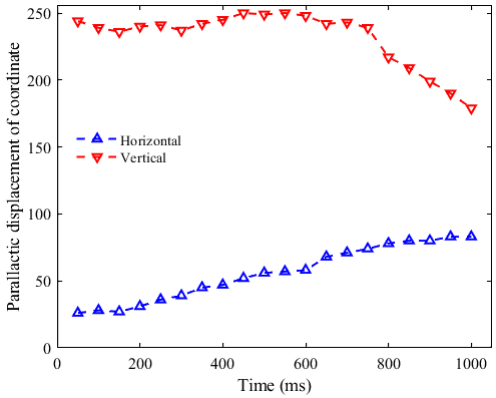


**Figure 3:** The coordinates of copper wire endpoint on 20 frames of the reconstructed image within a 1-second timeframe.

black is a result of the scattering noise generated by the camera during image capture. This noise is more pronounced when a smaller number of frames from the original image are used, leading to higher noise levels and a poorer signal-to-background ratio (SBR).

## IV. Conclusion

We have successfully achieved dynamic imaging of MNPs at a rate of 20 frames per second (FPS) using the MPOI method proposed in this study. The reconstructed image clearly distinguishes the MNPs and the copper wire based on their respective gray values, allowing real-time detection of the wire's movement trajectory. Moving forward, our research will focus on investigating the method's capability to penetrate living tissues, which holds great promise for contrast imaging of dynamic physiological processes.

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## Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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