Magnetophoresis & microfluidics for efficient magnetic nanoparticle manipulation

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Context

- Microfluidic magnetophoresis for effective separation & sorting for a broad range of clinical diagnostics & biomedical applications [1]
- Superparamagnetic Nano Particles (SNP) ⇒ high surface-to-volume ratio, ⇒ higly diffusive, ⇒ no sedimentation → **Increased interaction** with biological sample
- Micro magnet arrays ⇒ patterned & localized high magnetic field gadients ⇒ **Effective SNP manipulation** [2]
- **Low cost** & **upscalable fluidic chip fabrication** foreseeing future integration in biomedical devices

Physics

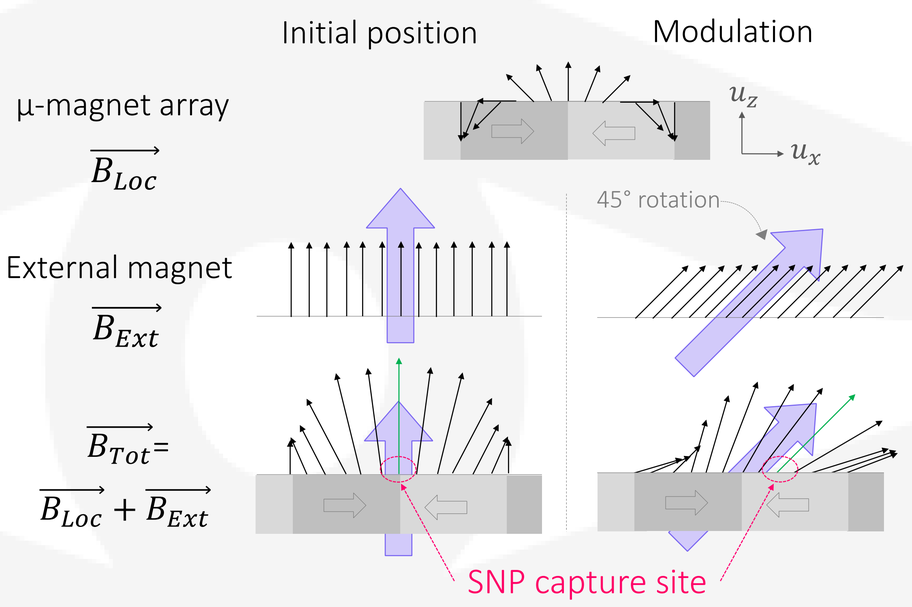
- Magnetophoresis occurs on magnetized particles in magnetic field gradients
  - Forces acting on SNP

$$\boldsymbol{F_{mag}} = \frac{V(\chi_{SPN} - \chi_{fluid})}{\mu_0}(\Delta.\boldsymbol{B})\boldsymbol{B}$$

$$\boldsymbol{F_{drag}} = 6\pi\eta R_{hyd}(\boldsymbol{v_{SPN}} - \boldsymbol{v_{fluid}})$$

Materials & Methods

Magnetophoresis implementation



⇒ 2 ways magnetic-viscous coupling **increase SNP capture kinetics** [3]
⇒ **SNP position control** with magnet position (°)
⇒ **SNP speed control** with magnet rotation speed (rpm)

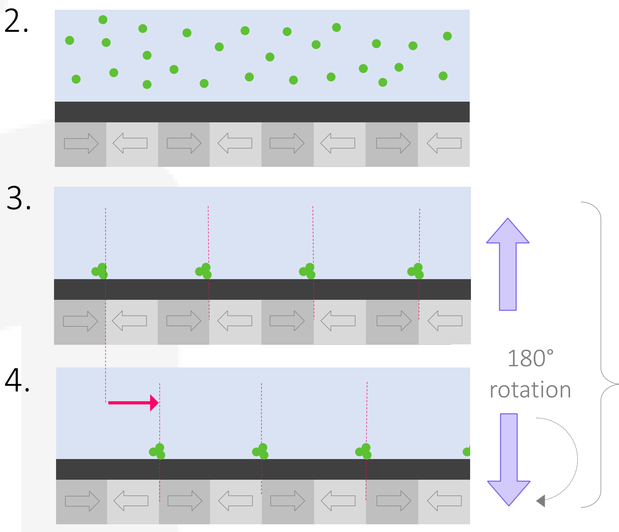
Experimental steps

1. Sample containing SNP injection
2. µmagnet array + spacing layer ⇒ SNP in suspension
3. External magnet ⇒ SNP capture on substrate (10 min)
4. External magnet rotation ⇒ magnetophoresis
5. Particle Image Velocimetry (PIV)

SNP characteristics

- 200 nm diameter
- 40% magnetite core
- Hydrophilic polymer matrix
- Fluorescent

Fluidic chamber cross sectional views



* *Chemicell GmbH Nano-screenMAG-ARA 200 nm*

Experimental parameters

SNP concentration	24 µg/mL
Buffer	Tris HCl 10 mM
Fluidic chamber volume	10 µL
Frame acquisition rate	1.6 fps

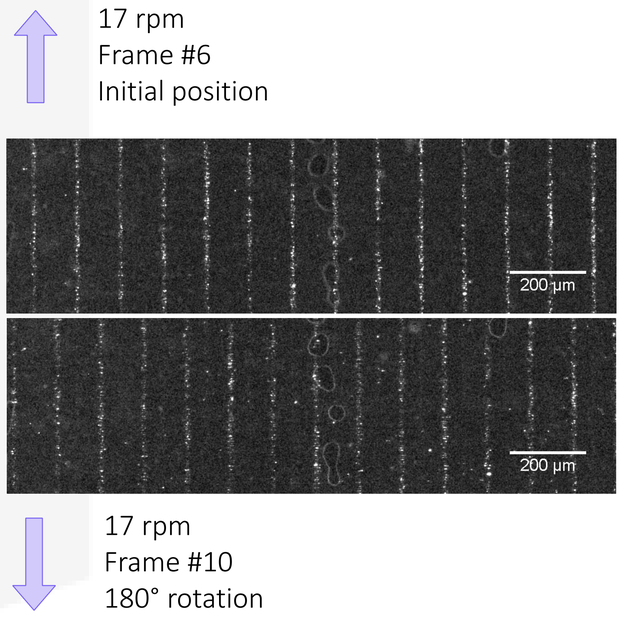
Magnetic field & forces acting on SNP

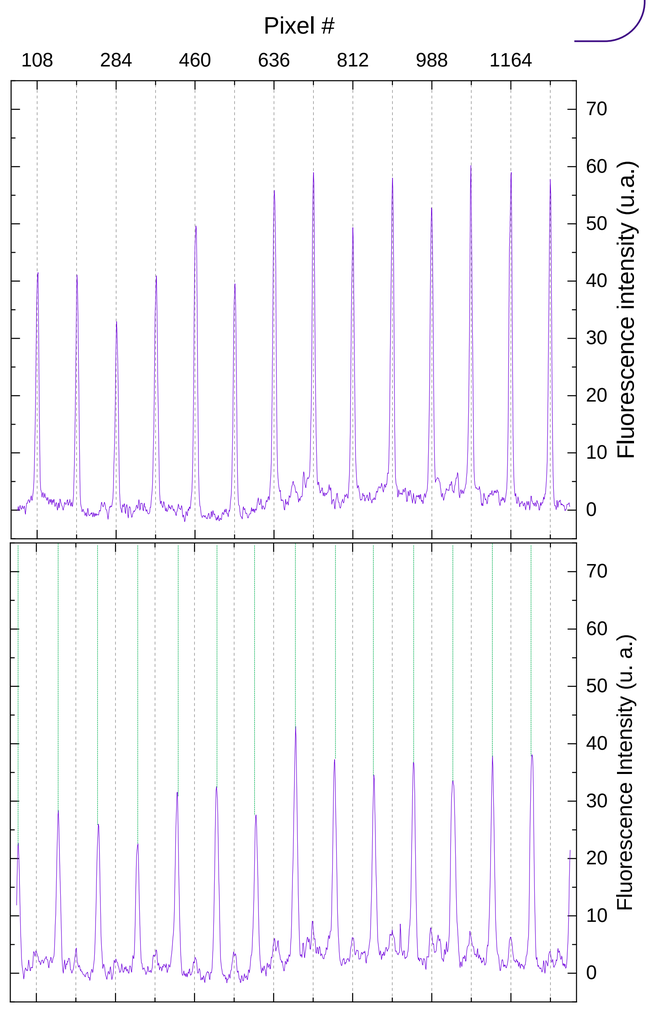
B_{loc}	10 mT
B_{Ext}	100 mT
$\partial B/\partial z$	1000 T/m**
$F_{mag,z}$	1 pN
$F_{mag,y}$	> $F_{drag,y}$
$F_{drag,y}$	57 fN***

Velocity range

	n= 4	n= 4
Voltage	0.9 V	11.9 V
Magnet rotation speed	17 rpm	304 rpm****
Theoretical velocity	32.0 ± 2.4 µm.s^{-1}	571.3 ± 43.7 µm.s^{-1}
Experimental velocity	30.3 ± 2.4 µm.s^{-1}	577.2 ± 20.5 µm.s^{-1}

** *Simulated at the surface of the substrate*
*** *Calculated for the SNP velocity extracted at 17 rpm*
**** *Linear rotation speed extrapolation*





Results

Conclusions & Perspectives

- ✓ **Fast SNP capture** on substrate
- ✓ **Precise SNP positioning** on substrate
- ✓ **mm/s range velocity & cm range transport distance**

⇒ SNP handling in different fluidic channels
⇒ Biological target capture & accurate manipulation
⇒ Synchronous detection

Potential for integrated *in vitro* diagnostics

References
1. Munaz, A., Shiddiky, M. J. A. & Nguyen, N.-T. Recent advances and current challenges in magnetophoresis based micro magnetofluidics. *Biomicrofluidics* **12**, 031501 (2018).
2. Fratzl, M., Delshadi, S., Devillers, T., Bruckert, F., Cugat, O., Dempsey N. M. & Blaire, G. Magnetophoretic induced convective capture of highly diffusive superparamagnetic nanoparticles. *Soft Matter* **14**, 2671-2681 (2018).
3. Cugat, O., Delamare, J. & Reyne, G. Magnetic micro-actuators and systems (MAGMAS). *IEEE Trans. Magn.* **39**, 3607–3612 (2003).

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