Mag-spinner: A next-generation Facile, Affordable, Simple, and porTable (FAST) magnetic separation system

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Manufacture of the Mag-spinner using a 3D-printer

Mag-spinner was manufactured by a 3D printer (Nobel Superfine, XYZprinting, Taiwan) and is composed of a spinning region, inlet, flow path, magnet, withdrawal region, and outlet.

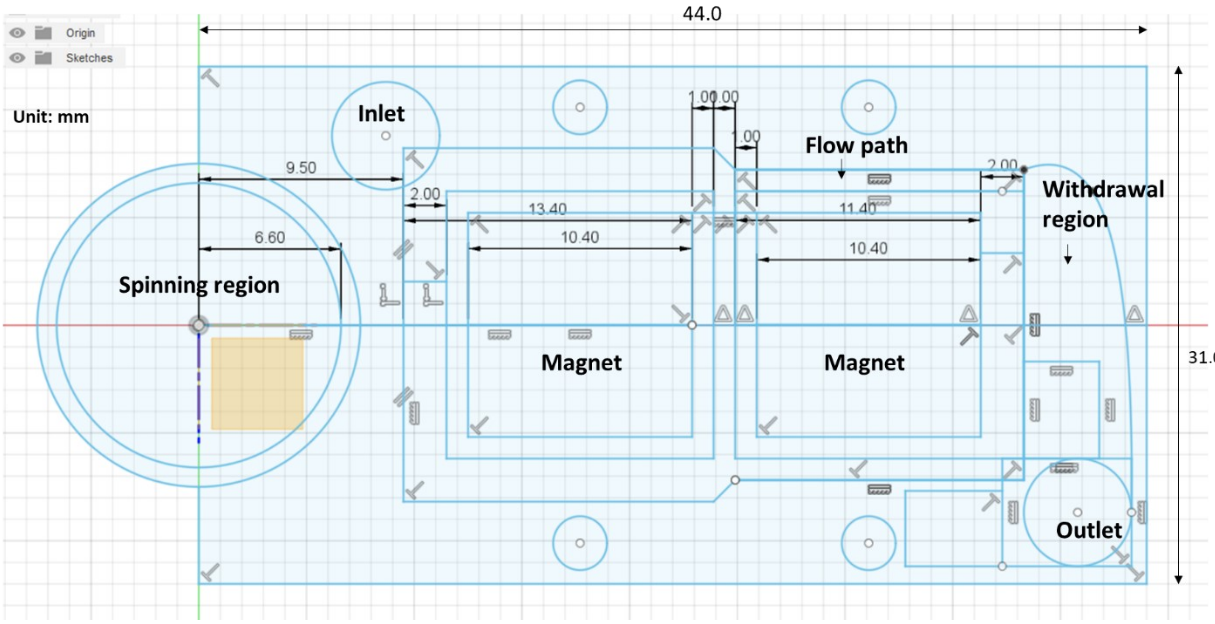

Figure S1. Blueprint of Mag-spinner.

Synthesis of the 7 nm iron oxide nanoparticles

The 7 nm iron oxide nanoparticles were synthesized in the solution phase at high temperature. A NaOH/dethylene glycol (DEG) stock solution was prepared by dissolving NaOH (1 g) in DEG (10 mL) and then heated at 120 °C for 1 h under Ar, cooled, and maintained at 70 °C. A mixture of polyacrylic acid (PAA, 5.184 g), $FeCl_3$ (0.065 g), and DEG (17 mL) was heated to 220 °C under nitrogen atmosphere for 30 min with vigorous stirring. The NaOH/DEG stock solution (1.75 mL) was then injected rapidly into this hot mixture, whereby the reaction solution slowly turned black. The resulting mixture was further heated for 2 h and then cooled to room temperature (RT).

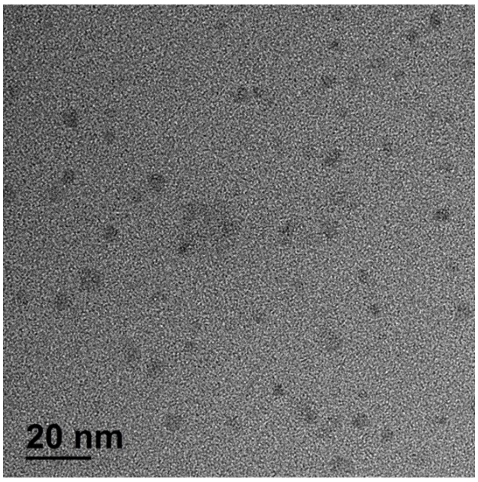

Figure S2. TEM image of the 7 nm iron oxide nanoparticles.

Measurement of the nanocluster (NC) surface charge

The NC surface charge was measured using a zetasizer (ZSU3200, Malvern PANalytical, England).The NCs are coordinated by PAA and possess a negative surface charge owing to the rich presence of PAA carboxylates.

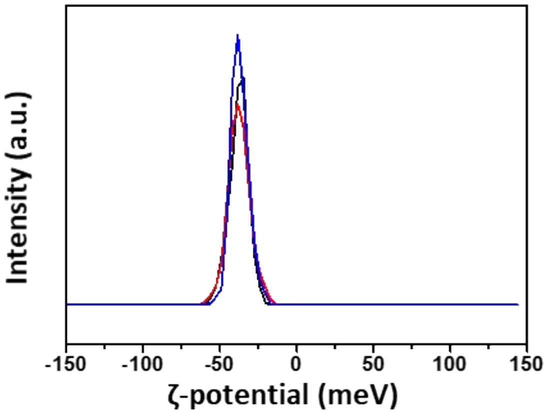

Figure S3. ζ-potential of the NCs.

Comparison of the hydrodynamic size of the NCs before and after magnetic attraction

The hydrodynamic size of the NCs was measured before and after magnetic attraction using a zetasizer (ZSU3200, Malvern PANalytical, England). No change in the hydrodynamic size of the NCs before and after magnetic attraction was observed.

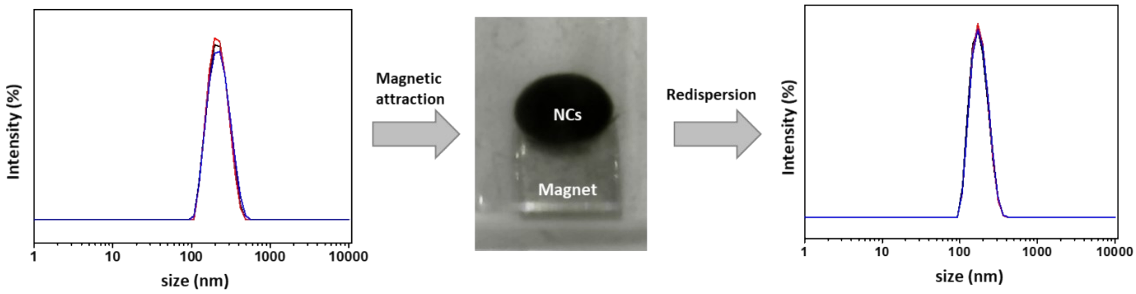

Figure S4. Hydrodynamic size of the NCs before and after magnetic attraction.

Test for the capture efficiency of 7 nm iron oxide by Mag-spinner

The mixture solution containing 7 nm iron oxide nanoparticles and green food coloring was spun in Mag-spinner. The attracted nanoparticles were observed around the magnet.

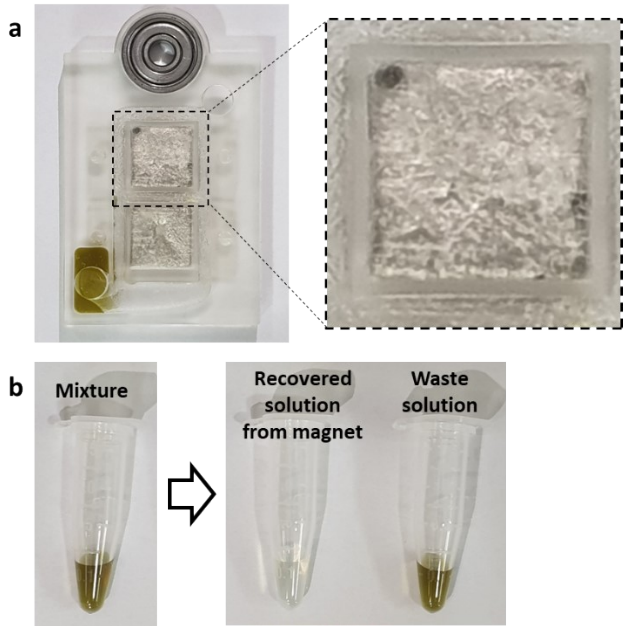

Figure S5. a) Image of Mag-spinner containing solutions with 7 nm iron oxide nanoparticles and green food coloring after spinning. b) Images of the original nanoparticles–green food coloring solution mixture, transparent NC solution recovered from the magnets, and green waste solution.

Simulation of the magnetic flux density around the magnets

The pulling force of the magnetic particles is described as

$$F_{pull} = nm\nabla B$$

$$m = \frac{4}{3}\pi\left(\frac{d}{2}\right)^2 M_{sat}$$

where n is the number of magnetic particles, m is the magnetic moment of particle, M_{sat} is the saturation magnetization, d is the diameter of a single magnetic core, and B is the variation in magnetic flux density, which is simulated using Finite Element Method Magnetics (FEMM, free software).

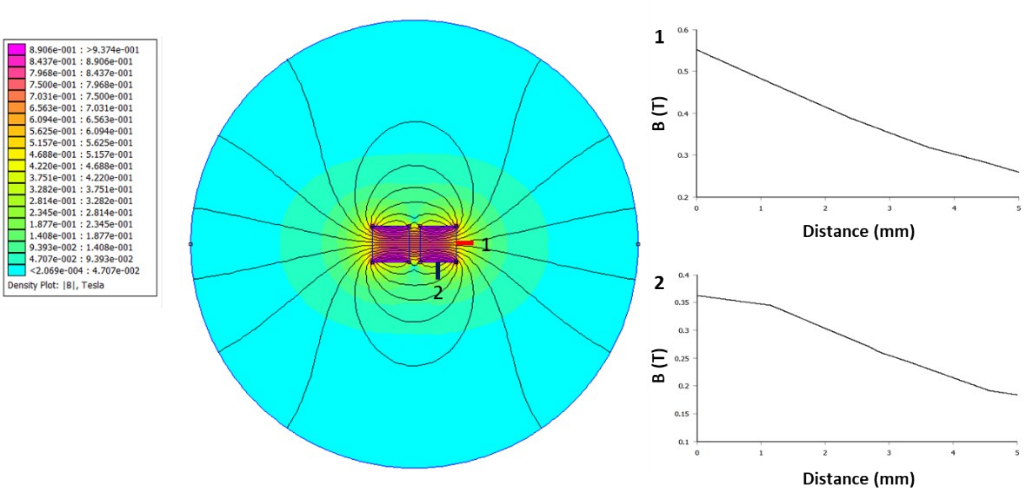

Figure S6. Density plot of the magnetic flux and graph of the magnetic flux density vs. distance from the magnet depending on the location (1 and 2).

Calculation of the NC drag force

The drag force of the magnetic particles near a magnet is defined as

$$F_D = 6\pi\eta r v$$

where η is the fluid viscosity, r is the hydrodynamic radius of the particles, and v is the fluid velocity. The drag force is directly proportional to the hydrodynamic radius and fluid velocity of the NCs. The hydrodynamic size of the NCs was measured as 232 nm and their average velocity was 9×10^{-6} m·s^{-1}. As a result, the NC drag force was calculated as 27.3×10^{-15} N.

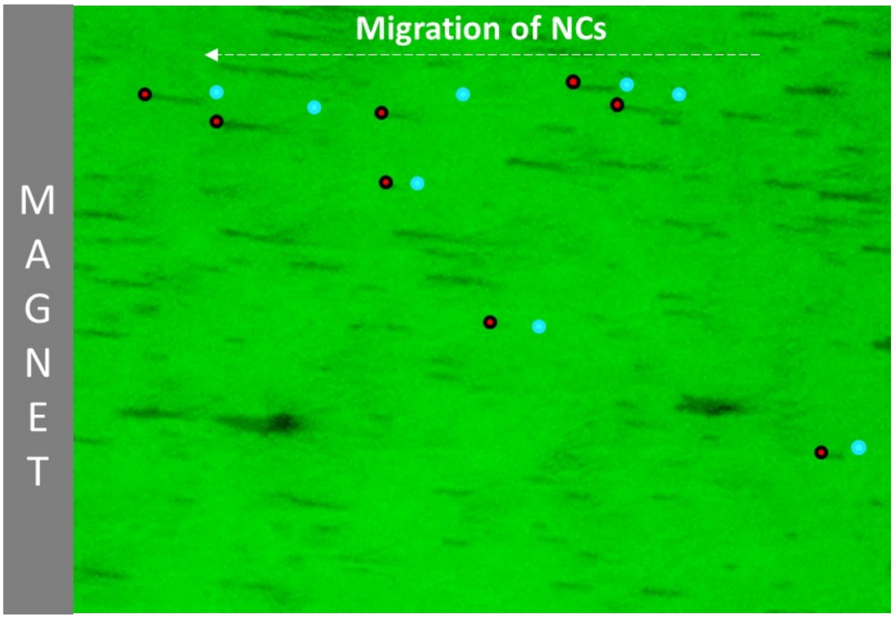

Figure S7. Image of the NCs attracted by a magnet in aqueous solution. Blue and red circles represent the starting and final points of NC movement, respectively.

Calculation of the centrifugal force applied on the NCs and 7 nm iron oxide nanoparticles in Mag-spinner

The magnitude of the centrifugal force on the particles is defined as

$$F = m\omega^2 r$$

where m is the mass of the particle, r is the distance from the center of the rotating parts (1–4 cm), and ω is the angular velocity (240 rpm).

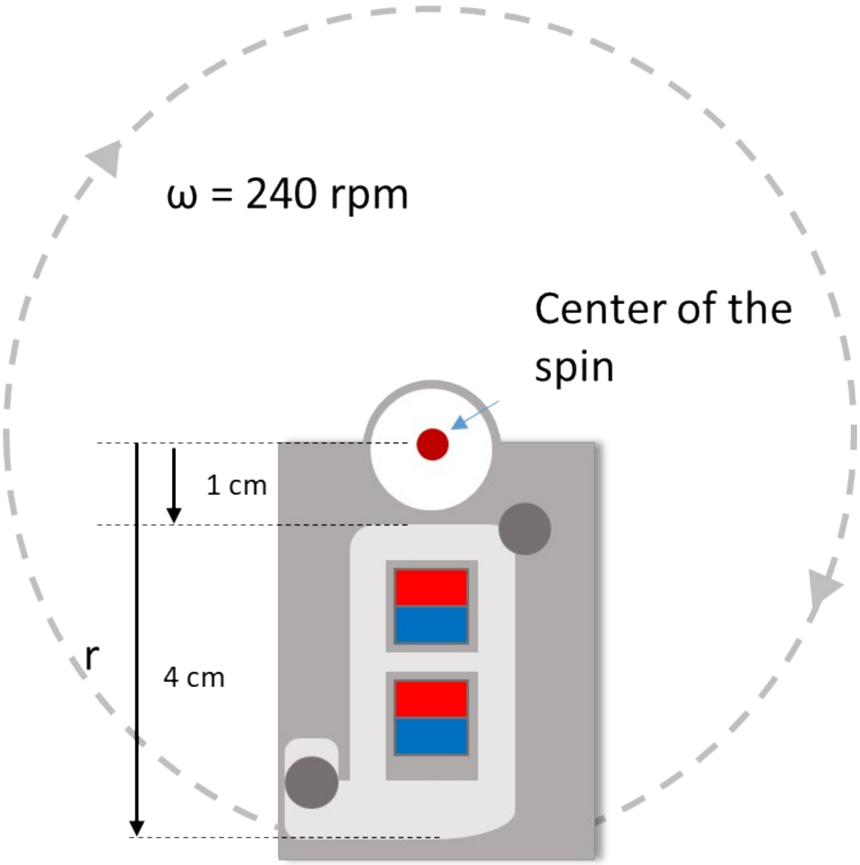

Figure S8. Factors that govern the centrifugal force.

Calculation of the pulling force and centrifugal force of the 7 nm iron oxide nanoparticles

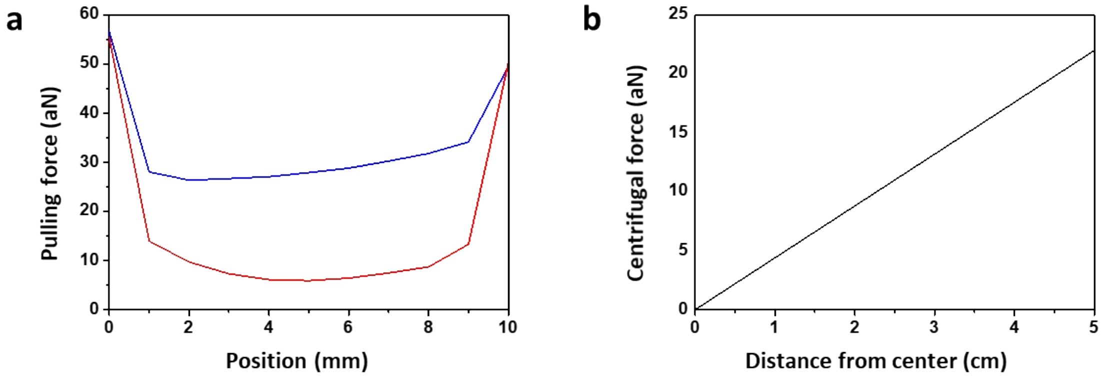

Figure S9. Calculated a) magnetic pulling force and b) centrifugal force applied on the 7 nm iron oxide nanoparticles.

Synthesis of the fluorescein isothiocyanate (FITC)-labeled silica nanoparticles

FITC-labeled silica nanoparticles were obtained by the Stöber method and the SiO_2 surface was further modified with amine groups. The obtained SiO_2 particles were spherical and ~850 nm in size.

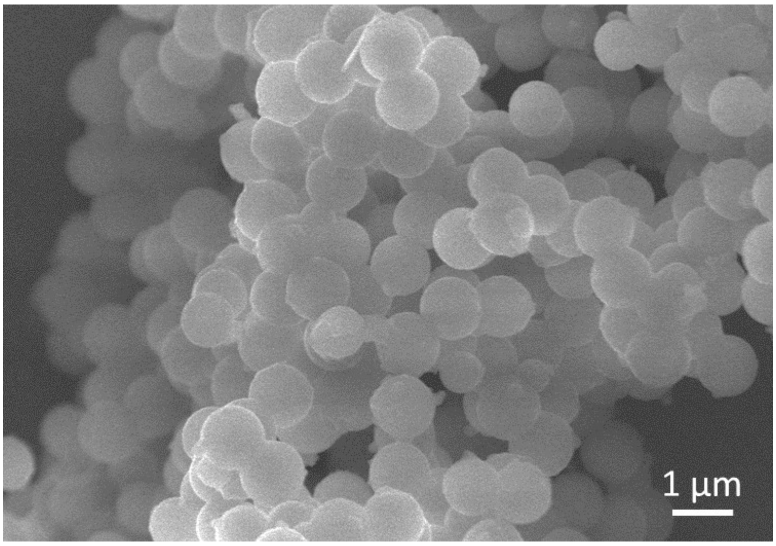

Figure S10. SEM image of the amine-FITC-SiO_2 particles.

Confirmation of the existence of cancer cells in the waste solution

The collected waste solution [Figure 6b (iii)] was cultured for 4 d in a CO_2 incubator. No recognizable cells were observed in the culture plate.

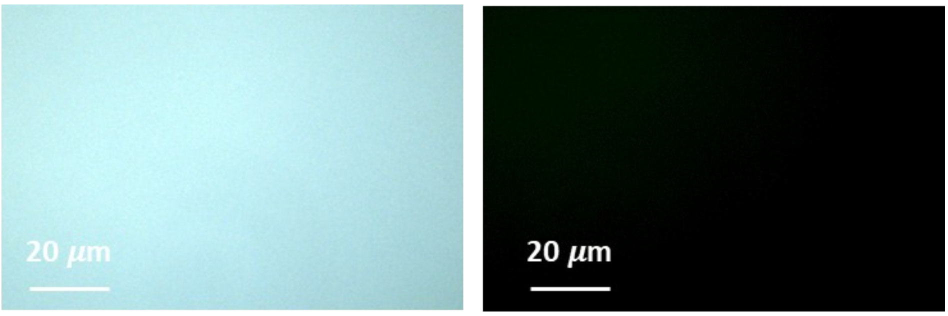

Figure S11. Bright-field and fluorescent images of the culture plate where the waste solution was cultured for 4 d.

Cell viability test after spinning in Mag-spinner

The influence of spinning on A549 cancer cells was evaluated *via* MTT assay. The A549 cells (5×10^4 cells) were spun in Mag-spinner, after which 10 µL of the MTT solution was added to each well (final concentration: 0.5 mg/mL). After incubation for 4 h, formazan, which is generated from the reduction of MTT by NAD(P)H-dependent oxidoreductase in living cells, was dissolved in the solubilization solution of the kit. The absorbance at 550 nm was obtained using a microplate reader (SpectraMax M2e, Molecular Devices, LLC, USA).

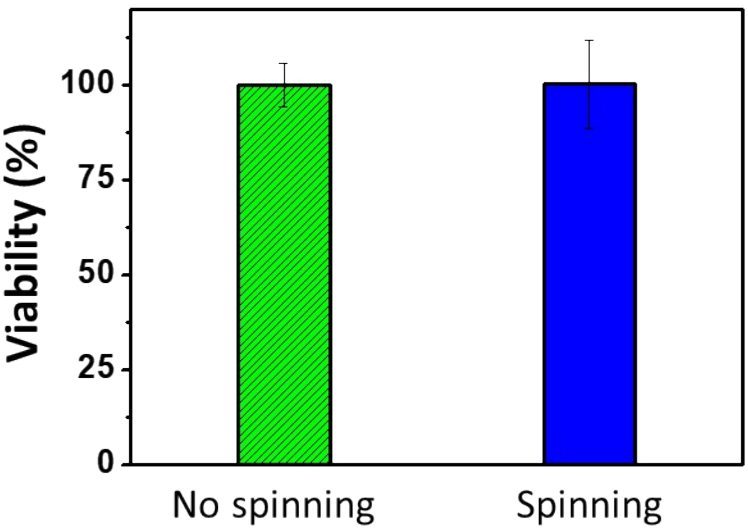

Figure S12. Viability comparison of A549 cells with (blue) and without (green) spinning in Mag-spinner.