Supporting Information

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A Magnetically and Electrically Powered Hybrid Micromotor in Conductive Solutions: Synergistic Propulsion Effects and Label-Free Cargo Transport and Sensing

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Supplementary Figures

Figure. S1. Numerical simulations of the magnetic field vector obtained for magnetization (A) normal (as used in our previous publications[6],[7]) and tangential (as used in current setup (Fig. 1(A)) to the metallo-dielectric interface of the JP where the metallic coated hemisphere consists also of a ferromagnetic 50nm Ni layer sandwiched in between 15nm Cr and 15nm Au on the external layer.
Fig.S2. The magnetic field vector (A) and gradient (B) induced by a block magnet and their corresponding spatial distribution along a horizontal line. The Janus particle in our experiments was located ~40mm away from the magnet’s edge.
Fig. S3 Simulation of normalized DEP force ($\nabla E^2_{\text{normalized}} = \nabla E^2 / \nabla E^2_{\text{max}}$) induced along the metallic coating of the Janus particle with diameter of 5 and 25 µm.
Figure. S4. Live K562 cell trapping and transport. (A) Sequential trapping and transport of intact K562 cells under 100kHz, 20V. (B) The trapped K562 cell under 100kHz, 20V remained intact for at least 120s. These experiments were performed within a 20% PBS, 80% sucrose solution (2.2-2.6mS/cm, pH: 7.31). (C) Transport of a live cell to (t=60s) and from (120s) a region containing doxorubicin (DOX)-loaded liposomes.

Figure. S5 Comparison of Annexin V staining of cells with different treatment: 5µM DOX (18hr), 0.5µM DOX (18hr), no DOX, and necrotic (H₂O₂ treated).
**Figure. S6. Experimental setup.** Two ITO-coated slides were separated by a 120 µm-thick silicone spacer. An external magnet was used to rotate the micromotor, while an electric field was used for micromotor alignment, electric propulsion and cargo manipulation. (A) Side view of the experimental chamber. (B) Cross section A–A, as visualized by the microscope.

**Table S1.** Numerical boundary conditions for Fig. 3G and Fig.4D.

| Boundary | conditions          |
|----------|---------------------|
| 1        | Open boundary p=0   |
| 2        | Open boundary p=0   |
| 3        | Open boundary p=0   |
| 4        | Moving wall         |
| 5        | Rotating wall       |
Table S2. Dielectrophoretic Trapping conditions of various cargos by the JP

| Cargo     | Cargo diameter (µm) | Cargo diameter (µm) | Solution | Solution pH | Conductivity (mS/cm) | E-Field       | DEP |
|-----------|---------------------|---------------------|----------|-------------|----------------------|---------------|-----|
| Polystyrene sphere | 15                  | 27                  | 0.001-0.01 M KCl | 0.1-1.3     | 6.14                 | 50kHz-1MHz   | nDEP|
|           | 10                  | 27                  | 0.001-0.01 M KCl | 0.1-1.3     | 6.14                 | 100kHz-1MHz  | nDEP|
|           | 5                   | 10                  | 0.001-0.01 M KCl | 0.1-1.3     | 6.14                 | 500kHz-1MHz  | nDEP|
|           | 3                   | 5                   | 0.001-0.005 M KCl | 0.1-0.7     | 6.14                 | 2MHz-20V     | nDEP|
| Necrotic K562 (mammalian cell) | 13-20               | 27                  | 10% PBS, 90% 300mM sucrose | 1-1.3       | 7.31                 | 1MHz-20V     | nDEP|
|           |                     |                     | 20% PBS, 80% 300mM sucrose | 2.2-2.6     | 7.31                 | 100kHz-20V   | nDEP|
| 5 µM DOX treated K562 (mammalian cell) | 13-20               | 27                  | 10% PBS, 90% 300mM sucrose | 1-1.3       | 7.31                 | 100kHz-20V   | nDEP|
| Intact K562 (mammalian cell) | 13-20               | 27                  | 20% PBS, 80% 300mM sucrose | 2.2-2.6     | 7.31                 | 100kHz-20V   | nDEP|
| RBCs      | Diameter: 7.5, thickness: 3 | 27                  | 10% PBS, 90% 300mM sucrose | 1-1.3       | 7.31                 | 1MHz-20V     | nDEP|
|           |                      |                     | 20% PBS, 80% 300mM sucrose | 2.2-2.6     | 7.31                 | 500kHz-1MHz  | nDEP|
| Rhodococcus (bacterial cell) | 1-2                 | 5                   | 10% PBS, 90% 300mM sucrose | 1-1.3       | 7.31                 | 6MHz-20V     | pDEP|

Supplementary videos

**Video 1.** Manipulation of a microbot by both electric field and external rotation magnetic field.
**Video 2.** Two scenarios showing low oscillation factor and high oscillation factor.

**Video 3.** The influence of magnetic rolling of the JP on its electric field velocity \( V_{\text{electric}} \) in conductive solution.

**Video 4.** Trapping and transport of a polystyrene (PS) particle, red blood cell (RBC) and bacteria.

**Video 5.** Selective trapping of a necrotic K562 cell in 10% PBS, 90% 300mM sucrose, under 1MHz, 20V.

**Video 6.** Manipulating late, early apoptotic and viable cells within 10% PBS, 90% 300mM sucrose under 100kHz, 20V.

**Video 7.** Trapping and transport of an intact and live K562 cell in 20% PBS, 80% 300mM sucrose, under 100kHz, 20V.

**Video 8.** Trapping and transport of an intact and live K562 cell in 1x PBS at 1MHz, 75V.