Supplementary Information

Advanced materials for micro/nanorobotics

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Table S1. 2D materials-integrated micro/nanorobots

	Composition and types	Powering mechanisms (Sources)	Active component	2D materials functionalities	Application (targets)	Ref.
TMDs (MoS_2)	MoS_2/Pt, MoS_2/Au tubular	Catalytic (H_2O_2)	Pt, Au	Bio-interactive surfaces, quencher, drug loading	Biosensing (miRNA-21, thrombin) Drug delivery	1
	MoS_2/TiO_2 microsphere	Light (λ = n.s.)	MoS_2/TiO_2	Velocity enhancement, broaden absorption	Pathogen eradication (E. coli)	2
	S. platensis/Fe_3O_4/MoS_2/Au helical	Rotational magnetic field	Fe_3O_4	Photothermal conversion (photo absorbent)	Photothermal cell ablation (MG-63 cell)	3
TMDs (WS_2)	WS_2 microsphere	Light (λ = 385 nm, 475 nm, 550 nm, 621 nm)	WS_2	Photothermal conversion	-	4
	WS_2/Pt, MoS_2/Pt tubular	Catalytic (H_2O_2)	Pt	Bio-interactive surfaces, quencher	Biosensing (Endotoxins, LPS)	5
	PCL/Pt/Fe/WS_2 microsphere	Catalytic (H_2O_2) Magnetic	Pt, Fe	Bio-interactive surfaces, quencher	Biosensing (Endotoxins, LPS)	6
	WS_2/Ni/Pt tubular	Catalytic (H_2O_2) Magnetic	Pt, Ni	NIR-photocatalytic activity	Photodegradation (Remazol Brilliant Blue R)	7
	WS_2-PANI/Pt tubular	Catalytic (H_2O_2)	Pt	Capacitive enhancement, on-demand delivery	On-demand circuit configuration	8
MXenes (Ti_3C_2)	TiO_2-Ti_3C_2/Pt 2D sheet	Light (λ = 365 nm), Catalytic (H_2O_2)	TiO_2-Ti_3C_2/Pt	UV light-driven propulsion, on-off motion, photodegradation	Photodegradation (TNT)	9
	$Ti_3C_2T_x$-Pt/TiO_2/γ-Fe_2O_3 2D sheet	Light (λ = 365 nm), magnetic	$Ti_3C_2T_x$-Pt/TiO_2/γ-Fe_2O_3	UV light-driven propulsion, on-off motion, electrostatic capture	Sensing (Nanoplastic, PS nanobeads)	10
Xenes (2D As)	2D As-Pt 2D sheet	Catalytic (H_2O_2)	Pt	Drug loading	Drug delivery	11
Xenes (BP)	BP–Pt microtubes	Catalytic (H_2O_2)	Pt	Velocity enhancement	-	12
	PS/BP/Pt/Fe_2O_3 microsphere	Catalytic (H_2O_2) Magnetic	Pt, Fe_2O_3	Bio-interactive surfaces, quencher	Biosensing (Cholera Toxin B)	13

	PS/BP/Pt or MnO_2/Fe_2O_3 microsphere	Catalytic (H_2O_2) Magnetic	Pt or MnO_2, Fe_2O_3	Velocity enhancement	-	14
Xenes (2D Ge)	2D Ge-GO/Pt tubular	Catalytic (H_2O_2)	Pt	Fluorescent labeling	-	15
Carbon nitrides (C_3N_4)	Pt-gC_3N_4 microsphere	Light (λ = n.s.)	Pt-gC_3N_4	UV-visible light-driven propulsion, on-off motion	-	16
	g-C_3N_4 tubular	Light (λ = 408 nm, 565 nm)	g-C_3N_4	Visible light-driven propulsion, on-off motion	Removal/FL sensing (Heavy metals)	17
	g-C_3N_4/C microsphere	Light (λ = 420 nm)	g-C_3N_4/C	Visible light-driven propulsion, on-off motion, photodegradation	Photodegradation (RhB)	18
	Fe/C_3N_4 microsphere	Light (λ = 532 nm), magnetic	Fe, C_3N_4	Visible light-driven propulsion, photodegradation	Photodegradation (CR(VI))	19
	Fe_3O_4/f-C_3N_4 microsphere	Light (λ = n.s.), magnetic	Fe_3O_4, f-C_3N_4	Visible light-driven propulsion, photodegradation	Photodegradation (tetracycline)	20
	g-C_3N_4/Fe_3O_4/KF tubular	Light (λ = 420 nm), magnetic	g-C_3N_4, Fe_3O_4	Visible light-driven propulsion, on-off motion, photodegradation	Photodegradation (RhB)	21
	PLA/Grp/Al/Ga/Fe_3O_4/C_3N_4 tubular	Catalytic (H_2O_2) Magnetic	Al, Ga	Photocatalytic activity	Photodegradation (Picric acid)	22
	PHI (CN_x) microsphere	Light (λ = 365 nm, 385 nm, 415 nm, 470 nm)	PHI (CN_x)	UV-visible light-driven propulsion, photocharging	Controlled drug release, FL tracking	23, 24
MPX_3 ($MnPS_3$)	MnPS3-Fe3O4 2D sheet	Rotational magnetic field	Fe_3O_4	Photocatalytic activity	Photodegradation (CPS, RhB)	25

Abbreviations: As, arsenene; BP, black phosphorus; CPS, chlorpyrifos; E. coli, Escherichia coli; FL, fluorescence; Ge, germanene; GO, graphene oxide; Grp, graphene; KF, kapok fiber; LPS, lipopolysaccharide; n.s., not specified; PANI, polyaniline; PCL, polycaprolactone; PHI, poly(heptazine imide); PS, polystyrene; RhB, Rhodamine B; TNT, trinitrotoluene.

Table S2. ZIF type MOF-based micro/nanorobots

	Composition and types	Powering mechanisms (Sources)	Active component	Maneuverability	MOF functionalities	Application (targets)	Ref.
ZIF-8	Fe_3O_4/Fe/ZIF/Pt microrods	Catalytic (H_2O_2)	Pt	Magnetic guidance	Porous crystalline framework	Water treatment (Uranium)	26
	ZIF microhelices	Rotational magnetic field	Ni	Magnetic steering	Porous crystalline framework Biocompatibility pH-responsive degradation	Drug delivery	27
	UCNPs/TAPP/ZIF-8/Catalase/GOx particles	Catalytic (H_2O_2)	Catalase	-	Porous crystalline framework Biocompatibility	Cancer cell therapy	28
	KF/c-Fe_2O_3/c-Al_2O_3/MnO_2/ZIF-8 microtube	Catalytic propulsion (H_2O_2)	MnO_2	Magnetic guidance	Porous crystalline framework	Water treatment (CR, DOC)	29
	Fe/ZIF-8/GelMA microhelices	Rotational magnetic field	Fe	Magnetic steering	Porous crystalline framework Biocompatibility pH-responsive degradation	Drug delivery	30
ZIF-67	ZIF-8/ZIF-67 Janus crystals	Catalytic (H_2O_2)	ZIF-67 (Co-site)	-	Catalytic activity	n.s.	31
	ZIF-67/Fe_3O_4 particles	Catalytic (H_2O_2)	ZIF-67 (Co)	Magnetic guidance	Catalytic activity Porous crystalline framework	Drug delivery	32
	ZIF-67 particles	Catalytic (H_2O_2)	ZIF-67	-	Catalytic activity Porous crystalline framework	Drug delivery	33
	ZIF-67/TPM Janus particles	Light-triggered ionic self-diffusiophoresis	ZIF-67	-	Catalytic activity Porous crystalline framework	Water treatment (Hg)	34
ZIF-L	cat-β/ZIF particles	Catalytic (H_2O_2)	Catalase	pH-regulated speed	Porous crystalline framework Biocompatibility	Drug delivery	35
	CAT-PDPA/ZIF-L particles	Catalytic (H_2O_2)	Catalase	pH-controlled buoyancy	Porous crystalline framework Biocompatibility	Drug delivery in 3D cell culture	36
ZIF-8, ZIF-67, ZIF-90, MOF-5	MOF/Au Janus particles	Self-diffusiophoresis, self-disintegration in water	ZIF-8, ZIF-67, ZIF-90, MOF-5	-	Porous crystalline framework Self-disintegration behavior	Antibacterial therapy (E. coli) Wound healing	37

Abbreviations: CAT, catalase; CR, congo red; DOC, doxycycline; DOX, doxorubicin; GOx, glucose oxidase; n.s., not specified; PDPA, poly (2-diisopropylamino)ethyl methacrylate; PS, polystyrene; TAPP, 5,10,15,20-tetrakis(4-aminophenyl)porphyrin; TPM, 3-trimethoxysilyl propyl methacrylate; UCNPs, upconversion nanoparticles; ZIF, Zeolitic imidazolate framework.

Table S3. UiO type MOF-based micro/nanorobots

	Composition and types	Powering mechanisms (Sources)	Active component	Maneuverability	MOF functionalities	Application (targets)	Ref.
UiO-66	Fe_3O_4/UiO-66/Pt colloidosomes	Catalytic (H_2O_2)	Pt	Magnetic guidance	Porous crystalline framework	Water treatment (MO, Cr (VI))	38
UiO-67	UiO-67-Co(bpy) particles UiO-67-Mn(bpy) particles	Catalytic (H_2O_2)	Co, Mn	Chemically controllable speed (Deceleration by chelation, IDA/EDTA)	Porous crystalline framework	n.s.	39
UiO-type Zr-fcu	Zr-fcu-azo/sti-30% crystals	Catalytic (H_2O_2)	Catalase	-	Porous crystalline framework	Water treatment (RhB)	40

Abbreviations: EDTA, ethylenediaminetetraacetic acid; IDA, iminodiacetic acid; MO, methyl orange; n.s., not specified; RhB, Rhodamine B; UiO, University of Oslo.

Table S4. MIL type MOF-based micro/nanorobots

	Composition and types	Powering mechanisms (Sources)	Active component	Maneuverability	MOF functionalities	Application (targets)	Ref.
MIL-100(Fe), MIL-125NH$_2$, UiO-66, ZIF-8	S. platensis/Fe_3O_4/Gelatin/ MOF microhelices	Rotational magnetic field	Fe_3O_4	Magnetic steering	Porous crystalline framework Biocompatibility Photocatalytic activity	Drug delivery Water treatment (RhB)	41
MIL-88B	MIL-88B/PPy/MB crystals	Self-diffusiophoresis and thermal convection	MIL/PPy/MB	pH-regulated motion	Porous crystalline framework Photocatalytic activity	Cancer cell therapy	42

Abbreviations: DOX, doxorubicin; MB, methylene blue; MIL, Materials Institute Lavoisier; PPy, polypyrrole; RhB, Rhodamine B; S. platensis, Spirulina platensis.

Table S5. Semiconducting metal oxides-based micro/nanorobots

Metal oxides	Fabrication techniques	Composition	Backbone material	E_g (eV)	Wavelength (nm)	Semiconductor functionalities	Application	Ref.
ZnO	Templated–assisted ALD	ZnO/Pt	ZnO microtubes	~3.2-3.4	200-360/390	Light-responsiveness	n.s.	43
	Templated–assisted ALD/electrodeposition	ZnO/Ni	ZnO microtubes			Light-driven propulsion	n.s.	44
	Chemical precipitation/ heat treatment/PVD	$ZnO/ZnO_2/Pt$	ZnO microspheres			Photocatalytic activity Light-driven propulsion	Water treatment	45
	Chemical precipitation/heat treatment/PVD	$ZnO/TiO_2/Pt$	ZnO microspheres			Light-driven propulsion	n.s.	46
	Chemical precipitation/PVD	ZnO/Pt	ZnO microparticles			Photocatalytic activity Light-driven propulsion	Water treatment	47
	Hydrothermal reaction/sputtering	ZnO/Au	ZnO microrods			Light-driven propulsion	n.s.	48
	Hydrothermal reaction/annealing/sputtering	ZnO/Pt	Hollow ZnO microspheres			Light-driven propulsion Phototactic motion	Cargo delivery	49
	Hydrothermal reaction/calcination	ZnO/ZnO_2	Yolk-shell ZnO microparticles			Light-driven propulsion	n.s.	50
	Hydrothermal reaction	ZnO/Ag	ZnO microstars			Photocatalytic activity Light-driven propulsion	Biofilm eradication	51
	Chemical precipitation	ZnO/Au	ZnO microstars			Photocatalytic activity Light-driven propulsion	Water treatment	52
	Hydrothermal reaction/polymerization	ZnO/Polysiloxane	ZnO microrods			Photocatalytic activity Light-driven propulsion	Water treatment	53
	Hydrothermal reaction/etching/E-beam evaporation	ZnO/Pt	ZnO microrods			Photocatalytic activity Light-driven propulsion	Water treatment	54
	FTS/sputtering/annealing/ HVPE	GaN/ZnO:Au	ZnO microneedles			Light-driven propulsion	n.s.	55

WO_3	n.s.	Galistan/WO_3	Galistan liquid metal marbles	~2.4-2.8	200-440/520	Light-driven propulsion	n.s.	56
	Hydrothermal reaction/calcination/sputtering	C/WO_3/Au	Carbon microspheres			Photocatalytic activity Light-driven propulsion	Water treatment	57
	Hydrothermal reaction/calcination	WO_3	WO_3 microspheres			Photocatalytic activity Light-driven propulsion	Water treatment	58
Fe_2O_3	Hydrothermal reaction/sputtering	Fe_2O_3/metal	Fe_2O_3 microspheres	~1.9-2.2	200-560/650	Photocatalytic activity Light-driven propulsion	Water treatment	59
	Chemical precipitation	α–Fe_2O_3	α–Fe_2O_3 microparticles			Phototactic motion Active assembly	n.s.	60
	Gel-sol methodology/ polymerization	Fe_2O_3/PTPM	Fe_2O_3 microspheres			Light-driven propulsion	n.s.	61
	Gel-sol methodology/ polymerization	Fe_2O_3/polysiloxane	Fe_2O_3 microparticles			Phototactic motion Active assembly	n.s.	62
	Hydrothermal reaction/sputtering	Fe_2O_3/Pt	Fe_2O_3 microspheres			Photocatalytic activity Light-driven propulsion	Water treatment	63
	Templated–assisted gel-sol method/ hydrothermal reaction/surface modification	MnO_2/SiO_2/γ–Fe_2O_3	SiO_2 microtubes			Photocatalytic activity Light-driven propulsion	Water treatment	64
	Hydrothermal reaction/wet chemistry	Halloysite/α–Fe_2O_3/Ag	Halloysite nanotubes			Photocatalytic activity Light-driven propulsion	Water treatment	65
β–FeOOH	PVD/ hydrolysis	PS/β–FeOOH/AgCl/Ag	PS microspheres	~2.0–2.5	200-500/620	Light-driven propulsion	n.s.	66, 67
Cu_2O	Chemical precipitation/sputtering	Cu_2O/Au	Cu_2O microspheres	~1.9-2.2	200-560/650	Light-driven propulsion	n.s.	68
	E-beam/annealing	SiO_2/TiO_2/Cu_2O	SiO_2 microspheres			Light-driven propulsion	n.s.	69
	Chemical precipitation	Cu_2O/N–CNT	Cu_2O microspheres			Light-driven propulsion Phototactic motion	n.s.	70

	Chemical precipitation	$Cu_{2+1}O$	$Cu_{2+1}O$ microparticles	~1.54	200-800	Light-driven propulsion	n.s.	71
Cu_2O	Chemical precipitation/calcination	Cu_2O	Cu_2O truncated micro–octahedrons	~1.9-2.2	200-560/650	Light-driven propulsion	n.s.	72
	Hydrothermal reaction	Cu_2O	Hollow Cu_2O miscrospheres			Photocatalytic activity Light-driven propulsion	Biofilm eradication	73
Rh_2O_3	Templated–assisted electrodeposition/annealing	Rh_2O_3–Au	Rh_2O_3–Au microrods	~1.41	200-880	Light-driven propulsion Phototactic motion	n.s.	74

Abbreviations: ALD, atomic layer deposition; FTS, flame transport synthesis; HVPE, hydride vapor phase epitaxy; N-CNT, N-doped carbon nanotubes; n.s., not specified; PS, polystyrene; PTPM, poly (3-methylthienyl methacrylate); PVD, physical vapor deposition.

Table S6. Semiconducting ternary metal oxides-based micro/nanorobots

Ternary metal oxides	Fabrication techniques	Composition	Backbone material	E_g (eV)	Wavelength (nm)	Semiconductor functionalities	Application	Ref.
BiOX	Templated–assisted PED/UV oxidation	CoNi/Bi_2O_3/BiOCl	Bi_2O_3/BiOCl microtubes	~3.60	180-360	Photocatalytic activity	Water treatment	75
	Self–assembly process/chemical precipitation	Chlorella cells/Fe_3O_4/BiOCl	Chlorella cells			Photocatalytic activity	Water treatment Bacterial inactivation	76
	Solvothermal method/photoreduction	$Fe_{0.11}Bi_{0.89}OBr$/Fe_3O_4/Mn_3O_4	$Fe_{0.11}Bi_{0.89}OBr$ microspheres	~2.9	200-430	Photocatalytic activity	Water treatment	77
	Chemical precipitation/sputtering	BiOI/Au	BiOI microspheres	~1.7	200-700	Light-driven propulsion	n.s.	78
	Hydrothermal reaction/chemical precipitation/sputtering	BiOI/AgI/Fe_3O_4/Au	BiOI microspheres			Photocatalytic activity Light-driven propulsion	Water treatment	79
	Chemical precipitation/electrostatic interaction	BiOI/Fe_3O_4	BiOI microspheres			Photocatalytic activity	Water treatment	80
	Co–precipitation method	BiOI/Fe_3O_4	BiOI microflakes			Photocatalytic activity Light-driven propulsion	Water treatment	81
	Templated–assisted electrodeposition	rGO/ZnO/BiOI/Co-Pi/Pt	rGO microtubes			Photocatalytic activity	Water treatment	82
Bi_2WO_6	Hydrothermal reaction/calcination	Bi_2WO_6	Bi_2WO_6 microspheres	~2.8	200-440	Photocatalytic activity Light-driven propulsion	Environmental remediation	83
$BiVO_4$	Coprecipitation method/hydrothermal reaction	$BiVO_4$	$BiVO_4$ microstars	~2.4	200-520	Photocatalytic activity Light-driven propulsion	Bacterial inactivation	84
	Solvothermal method	$BiVO_4$	$BiVO_4$ microsquares			Light-driven propulsion	n.s.	85

	Solvothermal method	$BiVO_4$	$BiVO_4$ microspheroids		Light-driven propulsion Active assembly	n.s.	86
	Coprecipitation method/hydrothermal reaction	$BiVO_4$	$BiVO_4$ microspheres with concave defects		Photocatalytic activity Light-driven propulsion	Therapeutics	87
	Hydrothermal reaction	$BiVO_4$	$BiVO_4$ microrods		Photocatalytic activity Light-driven propulsion	Water treatment	88
	Hydrothermal reaction	$BiVO_4$/GO	$BiVO_4$/GO microspheres		Photocatalytic activity Light-driven propulsion	Water treatment	88
	Coprecipitation method/hydrothermal reaction/electrostatic interaction	$BiVO_4/Fe_3O_4$	$BiVO_4$ microstars		Photocatalytic activity Light-driven propulsion	Food treatment Water treatment	89, 90
	Coprecipitation method/hydrothermal reaction/electrostatic interaction	PEI/Fe_3O_4/$BiVO_4$	PEI/Fe_3O_4 clusters		Photocatalytic activity	Biofilm eradication	91

Abbreviations: GO, graphene oxide; n.s., not specified; PED, pulse electrodeposition; PEI, polyethylenimine.

Table S7. Semiconducting quantum dot (QD)- and metal chalcogenide-based micro/nanorobots

Ternary metal oxides	Fabrication techniques	Composition	Backbone material	E_g (eV)	Wavelength (nm)	Semiconductor functionalities	Application	Ref.
QDs	Templated–assisted electrodeposition	ZnS or CdS QDs/PANI/Pt	PANI/Pt microtubes	~3.8	200-330	Photocatalytic activity	Water treatment	92
	Templated–assisted electrodeposition	CdS QDs/C_{60}/Pt, Pd or MnO_2	C_{60} microtubes	~2.9	200-430	Light-responsiveness	n.s.	93
	Oil–in–water emulsion	CdTe@ZnS or CdSe@ZnS QD_S/Fe_3O_4/PCL	PCL shells	~2.3	200-540	Photocatalytic activity Light-driven propulsion	Water treatment	94
	Oil–in–water emulsion	CdSe@ZnS/Fe_3O_4/ PCL/ PLGA	PCL/PLGA shells	n.s.	n.s.	Photocatalytic activity Light-driven propulsion	Water treatment	95
	Chemical precipitation/in–situ deposition	Cu_2O/CdSe	Cu_2O truncated micro–octahedrons	~2.3	200-540	Light-driven propulsion	Water treatment	96
	Hydrothermal reaction	Cu_2O/PbS	Cu_2O micro–octahedrons	~0.6-1.6	IR	Light-driven propulsion Fluorescence	n.s.	38
No QDs	Hydrothermal reaction/ion–exchange reaction/in–situ deposition/ALD/etching	TiO_2/Fe_3O_4/CdS	CdS microtubes	~2.9	200-430	Photocatalytic activity Light-driven propulsion	Water treatment	97
	Microwave reaction	Sb_2S_3	Sb_2S_3 microrods	~1.6-1.8	200-680/700	Photocatalytic activity Light-driven propulsion	Water treatment	98
	PVD/ALD	Sb_2Se_3/ZnO	Sb_2Se_3 nanowires	~1.6	200-700	Light-driven propulsion	n.s.	99

						Polarotactic navigation		
	PVD/cation exchange reaction /sputtering	$Zn_XCd_{1-X}Se/Cu_2S/Pt$	$Zn_XCd_{1-X}Se$ nanowires	~1.7-2.7	200-460/730	Light-driven propulsion	n.s.	100
	Hydrothermal reaction/sputtering	$CuS/Fe_3O_4/Pt$	CuS microspheres	~2.1	200-600	Phototactic motion Photocatalytic activity	Water treatment	101
	Hydrothermal reaction/photochemical deposition	$ZnIn_2S_4/Pt$	$ZnIn_2S_4$ microspheres	~2.08-2.48	200-500/600	Photocatalytic activity Light-driven propulsion	Water treatment	102

Abbreviations: ALD, atomic layer deposition; n.s., not specified; PANI, polyaniline; PCL, polycaprolactone; PLGA, polylactic-co-glycolic acid; PVD, physical vapor deposition.

Table S8. Polymer-based micro/nanorobots

	Polymer types	Actuation sources	Polymer functionalities	Application	Ref.
Smart responsive polymers	PNIPAM-co-ABP-AAc	Magnetic field, temperature	Remote-controlled capture, transport, and release	Sperm cell delivery	103
	PNIPAM	Catalytic (H_2O_2), temperature	Temperature-controlled speed regulation	n.s.	104
	PTBC	Rotational magnetic field, temperature	Pick up and dispose of chemicals	Water treatment (arsenic, atrazine)	105
	PDPA	Catalytic (H_2O_2), pH	pH-controlled buoyancy	Drug delivery in 3D cell culture	36
	Liquid-crystal elastomers with azobenzene dye	Light	Light-controlled motion	n.s.	106
	pNIPAM, pNIPAM-AAc	Rotational magnetic field, temperature, pH	Temperature/pH-responsive structural change	on-demand active cargo delivery	107
Porous organic polymers	Py-Azine COF	Catalytic (H_2O_2), magnetic field	Fluorescent labeling	Sensing (TNP)	108
	TAPB-PDA-COF TpAzo-COF	Light	Light-driven propulsion Biocompatibility Drug loading	Drug delivery	109
	porphyrin-COF	Light	Light-driven propulsion Biocompatibility	Cancer therapy	110
	Conjugated organic polymeric networks	Light	Light-driven propulsion Photocatalytic activity	Photodegradation (RhB, MB, MO) pH chemosensors	111
	Conjugated organic polymeric networks	Light	Light-driven propulsion Photocatalytic activity	Photodegradation (MDMA)	112
Conductive polymers	PANI	Catalytic (H_2O_2)	Conductive carrier layer	On-demand circuit configuration	8
	PPy	Catalytic (H_2O_2), magnetic field	Programmable surface property	Water treatment (α-oestradiol)	113

	PPy	Light	Programmable surface property	Cancer cell therapy	42
	PEDOT	Catalytic (H_2O_2), ultrasound	Conductive carrier layer	n.s.	114, 115

Abbreviations: COF, covalent organic frameworks; MB, methylene blue; MDMA, 3,4-methylenedioxymethamphetamine; MO, methyl orange; n.s., not specified; PANI, polyaniline; PDPA, poly (2-diisopropylamino)ethyl methacrylate; PEDOT, poly(3,4-ethylene dioxythiophene); pNIPAM-AAc, poly N-isopropylacrylamide acrylic acid; PNIPAM-co-ABP-AAc, poly(N-isopropylacrylamide)-co-acryloylbenzophenone-co-(acrylic acid); PNIPAM, poly(N-isopropyl acrylamide); PPy, polypyrrole; PTBC, pluronic tri-block copolymer; RhB, rhodamine B; TNP, 2,4,6-trinitrophenol.

Table S9. Biological cell hybrid micro/nanorobots

Types of biological cells	Species	Propulsion and navigation	Functional hybrid	Applications	Ref.
MTB	*M. magneticum* strain AMB-1	Autonomous + magnetotaxis			116, 117
	M. magneticum strain AMB-1	Autonomous + magnetotaxis		Organic compound removal	
	M. magneticum strain AMB-1	Autonomous + magnetotaxis	Fe_3O_4 NPs		118
	M. magneticum strain AMB-1	Autonomous + magnetotaxis	Photosensitizer NPs	Cancer therapy	119
	M. magneticum strain AMB-1	Autonomous + magnetotaxis		Drug delivery	120
	Magnetococcus marinus MC-1	Autonomous + magnetotaxis	Liposomes	Drug delivery	121
	M. gryphiswaldense MRS-1	Autonomous + magnetotaxis	Mesoporous silica microtube	Biofilm eradication	122
E. Coli.	*E. coli* MG1655	Autonomous	Liposome microparticles	Drug delivery	123
	E. coli MG1655	Autonomous + magnetotaxis	RBC/Fe_3O_4 NPs	Drug delivery	124
	E. coli MG1655	Autonomous + chemotaxis + magnetotaxis	PEM-MNP microparticles	Drug delivery	125
Mammalian cell	C2C12 myoblast	Electric pulse stimulation	PDMS-based hydrogel		126
	Embryonic stem cells and C2C12 myoblasts	External light stimuli	PDMS scaffold		127
	C2C12 myoblast	Bio-actuator	Polymer-based Flexible 3D Printed Bio-Bot Skeletons		128
	Mesenchymal stem cells	Extrinsic (magnetic)	PLGA microscffold with magnetic cluster	Knee cartilage regeneration	129

	PC12 cells	Magnetotaxis	Piezoelectric magnetic microswimmer	Targeted cell therapy	130
	Macrophage	Extrinsic (magnetic)	PLGA-DTX- Fe_3O_4 NPs	Cancer Therapy	131
Sperm	Bovine sperm cells	Magnetotaxis	Tetrapod microstructures	Drug delivery	132
	Bull sperm cells	Magnetotaxis	Magnetic microtubes	Drug delivery	133
	Bovine sperm cells	Magnetotaxis	Fe_2O_3 particles	Drug delivery	134
	Human sperm	Magnetotaxis	CPT-coated magnetic cap	Cancer therapy	135
	Bovine sperm cells	Magnetotaxis	4D printed sperm microcarriers via two-photon polymerization	Assisted fertilization	136
	Bovine sperm cells	Magnetotaxis	Iron oxide-polystyrene composite particles	Assisted fertilization	137
Microalgae	*C. reinhardtii*	Autonomous	ACE2 receptor	Pathogen removal	138
	C. reinhardtii	Autonomous	Antibiotic polymeric NPs	Drug delivery	139
	C. reinhardtii	Autonomous + magnetotaxis	Magnetic PS microparticles	Drug delivery	140
	C. reinhardtii	Autonomous + phototaxis	Chitosan–nanoparticle matrix	Drug delivery	141
	Spirulina	Magnetotaxis	Fe_3O_4 NPs	Drug delivery, Imaging	142
Pollen/spore	Sunflower sporopollenin exine capsule	Extrinsic (chemical)	Pt layer	Heavy metal removal	143
	Pollen grains (dandelion, pine, lotus, etc)	Extrinsic (chemical)	Pt layer	Environmental remediation/ drug delivery	144

	Sunflower pollen	Extrinsic (magnetic)	Au/Co/Au layer	Cancer therapy	145
	Sunflower pollen	Extrinsic (magnetic)	Magnetic liquid metal droplets	Biofilm eradication	146
	Fungi spore	External (Magnetic)	Fe_3O_4 NPs	Heavy metal removal	147
	Ganoderma lucidum spore	External (Magnetic)	Fe_3O_4 NPs /Carbon dots	Pathogen removal	148
Plant callus	Tomato callus	Extrinsic (magnetic)	Fe_3O_4 NPs	Drug delivery	149
	Tomato callus	Extrinsic (magnetic)	Fe_3O_4 NPs	Organic compound removal	150

Abbreviations: ACE2, angiotensin-converting enzyme 2; C. reinhardtii, Chlamydomonas reinhardtii; E. coli, Escherichia coli; M. gryphiswaldense MRS-1, Magnetospirillum gryphiswaldense MSR-1; M. magneticum strain AMB-1, Magnetospirillum magneticum strain AMB-1; MNP, magnetite nanoparticles; PEM, polyelectrolyte multilayer; PS, polystyrene.

Table S10. Advanced material-based micro/nanorobots: various designs, fabrication techniques, and size ranges

Design	Composition	Fabrication techniques	Size	Ref.
Synthetic advanced materials	ZIF-67 particles	In situ biomineralization	140 nm	33
	As-Pt 2D sheet	Sputtering	200-500 nm	11
	TABP-PDA-COF particles	Chemical method	452 ± 74 nm	109
	WO_3 microparticles	Hydrothermal reaction/calcination	1-2 μm	58
	MOF/Au Janus particles	Chemical method	1.6-3 μm	37
	$MnPS_3$-Fe_3O_4 2D sheets	Electrostatic assembly	2-5 μm	25
	Bi_2WO_6 microspheres	Hydrothermal reaction/calcination	~7 μm	83
	$BiVO_4$ microstars	Coprecipitation method/hydrothermal reaction	4-8 μm	84
	Zr-fcu-azo/sti-30% crystals	Chemical method	5-10 μm	40
	$Ti_3C_2T_x$-Pt/TiO_2/γ-Fe_2O_3 2D sheets	Thermal annealing/e-beam evaporation	5-10 μm	10
Microsphere robots	PHI (CN_x)/Pt, PHI (CN_x)/Au	Thermal polymerization/sputtering	1-3 μm	23
	MoS_2/TiO_2	E-beam evaporation	1-4.5 μm	2
	PHI (CN_x)	Thermal polymerization	1-5 μm	24
	Fe_3O_4/f-C_3N_4	Thermal polymerization/solvothermal	5-10 μm	20

	Fe_3O_4/UiO-66/Pt colloidosomes	Transient Pickering emulsion method	5-10 μm	38
	PCL/WS_2/Pt/Fe	Oil-water emulsion	~20 μm	6
	PS/Au/BP	Sputtering/Au-S bonding	~20 μm	13 14
	CdSe@ZnS/Fe_3O_4/PCL/PLGA	Oil–in–water emulsion	10-25 μm	94
Tubular robots	Conjugated organic polymeric networks	Sol-gel method/Glaser-type polycondensation reactions	d: 2.5 μm, L:~17.5 μm	112
	MoS_2/Pt, MoS_2/Au	Template-assisted electrodeposition	d: 5 μm, L:~20 μm	1
	g-C_3N_4/Fe_3O_4/KF	Thermal polymerization/chemical reduction	d: ~20 μm, L:>50 μm	21
	g-C_3N_4	Hydrothermal reaction/calcination	d: 9.7±1.5 μm, L: 67±14 μm	17
Helical robots	S. platensis/Fe_3O_4/MoS_2/Au	Biotemplating/hydrothermal reaction	~50 μm	3
	Fe/ZIF-8/GelMA microhelices	Two-photon polymerization stereolithography	50-100 μm	30
Biohybrid microrobots	Macrophage	Cell culture	300 nm	131
	E. coli MG1655	Bacteria culture	2 μm	124
	E. coli MG1655	Bacteria culture	2 μm	125
	M. magneticum strain AMB-1	Bacteria culture	2.5 μm	120
	M. magneticum strain AMB-1	Bacteria culture	3 μm	119

	C. reinhardtii	Microalgae Culture	10 μm	139
	C. reinhardtii	Microalgae Culture	10 μm	140
	Pollen grains (dandelion, pine, lotus, etc)	Natural products (commercial)/Sputtering	22-62 μm	144
	Tomato callus	Callus cultivation	30–70 μm	150
	Bovine sperm cells	Incubation	60–70 μm	134
	Bovine sperm cells	Incubation	60–70 μm	136
	Mesenchymal stem cells	Cell culture	357.55 μm	129

Abbreviations: As, arsenene; COF, covalent organic frameworks; GelMA, gelatin methacryloyl; PHI, poly(heptazine imide); S. platensis, Spirulina platensis; ZIF: zeolitic imidazolate framework.

Table S11. Advanced material-based micro/nanorobots: comparison of speed by different energy sources

Energy sources	Propulsion mechanism	Type	Size (μm)	Speed (μm/s)	Speed (body length/s)	Ref.
Catalytic	Catalytic, bubble propulsion	Zr-fcu-azo/sti-30% crystals	7.5		4	40
	Catalytic, ionic diffusiophoresis	MOF/Au Janus particles	2	17.2	8.6	37
	Catalytic, bubble propulsion	MoS_2/Pt microtubes	10	370	37	1
	Catalytic, bubble propulsion	ZIF-67 particles	0.14	8	57	33
	Catalytic, bubble propulsion	Fe_3O_4/UiO-66/Pt colloidosomes	7.5	450	60	38
	Catalytic, bubble propulsion	PANI/Pt microtubes	8	3000	375	151
Light	Light, self-diffusiophoresis	Conjugated organic polymer microtubes	17.5	7.04	0.4	112
	Light, photocatalytic bubble propulsion	g-C_3N_4 microtubes	67	72	1.1	17
	Light, self-electrophoresis	$BiVO_4$ microspheres	5.1		1.1	87
	Light, self-electrophoresis	$Ti_3C_2T_x$-Pt/TiO_2/γ-Fe_2O_3 2D sheets	7.5	16	2.1	10
	Light, photocatalytic	PHI (CN_x) microparticles	2.5	23	9.5	24
	Light, photocatalytic	TABP-PDA-COF particles	0.452	16.4	36	109
	Light, photothermal	WS_2 microparticles	0.8	6000	7500	4
Magnetic	Magnetic, tumbling	$MnPS_3$-Fe_3O_4 2D sheets	3	4.9	1.6	25

	Magnetic, tumbling	$Fe_3O_4/Bi_2O_3/Ag$ microrods	6.9	13.2	1.9	152
	Magnetic, corkscrew motion	ZIF microhelices	25	50	2	27
	Magnetic, tumbling	pNIPAM/ pNIPAM-AAc/FePt microparticles	120	532	4.4	107
Acoustic	Ultrasound	PPy microrods	5	30	6	153
	Ultrasound	Au/Ru/Pt nanorods	2	200	100	154
	Ultrasound	Au/Ru/Rh nanorods	2	200	100	155
	Ultrasound	Bubble-carried PEDOT/MnO_2 microtubes	10	50000	5000	115
Biohybrids	Extrinsic (magnetic)	Mesenchymal stem cells	357.6	2.88	0.01	129
	Magnetotaxis	Bovine sperm cells	60	6.8	0.11	134
	Extrinsic (magnetic)	Tomato callus	50	6.02	0.12	150
	Magnetotaxis	Bovine sperm cells	60	7	0.17	136
	Autonomous + magnetotaxis	*M. magneticum* strain AMB-1	3	13.3	4.4	119
	Extrinsic (chemical)	Pollen grains (dandelion, pine, lotus, etc)	42	200	4.8	144
	Autonomous + magnetotaxis	*E. coli* MG1655	2	10.2	5.1	124
	Autonomous + magnetotaxis	*C. reinhardtii*	10	51.44	5.1	140

	Autonomous + magnetotaxis	*M. magneticum* strain AMB-1	2.5	20.5	8.2	120
	Autonomous	*C. reinhardtii*	10	104.6	10.5	139
	Autonomous + chemotaxis + magnetotaxis	*E. coli* MG1655	2	22.5	11.3	125

Abbreviations: COF, covalent organic frameworks; E. coli, Escherichia coli; PHI, poly(heptazine imide); pNIPAM-AAc, poly N-isopropylacrylamide acrylic acid; PNIPAM, poly(N-isopropyl acrylamide); PPy, polypyrrole; ZIF: zeolitic imidazolate framework.

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