Electronic Supplementary Information (ESI):

Transportation and release of Janus micromotors by two-stage rocket hydrogel

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Supplementary videos description:

Video 1: The motion of hydrogel block without Janus micromotors loading (length: 10 mm, diameter: 3 mm, fuel: 10% H_2O_2)

Video 2: The motion of two-stage hydrogel rocket (length: 10 mm, diameter: 3 mm, fuel: 10% H_2O_2)

Video 3: The motion of two-stage hydrogel rockets with varied length and diameter in 10% H_2O_2.

Video 4: The self-propulsion of Janus micromotors in different environment (pure water, 10% H_2O_2 and released from two-stage hydrogel rocket).

Experimental methods

Janus Micromotors. To prepare Janus micromotors, polystyrene microspheres (PS, average diameter: 8.5 μm, J&K Chemical Ltd.) were used as the precursor particles. Briefly, 20 μL of PS aqueous dispersion (2.5 wt% and 1.04 g/cm^3) was first mixed with 100 μL of ethanol. The particle dispersion was then cast onto a glass slide and dried at room temperature to form a particle monolayer. The spreading microspheres were sputter deposited with a thin platinum layer using a Quorum Q150T ES Sputter Coater for 180 s. Subsequently, the hemispherical coated particles were released from the glass slide via gently washing with ethanol and ultrasonication for 5 seconds. After ethanol evaporated at ambient temperature, the obtained Janus micromotors were redispersed in 20 μL deionized water.

Two-Stage hydrogel rocket. The fabrication of two-stage hydrogel rocket involves the following steps. A double crosslinking (DC) hydrogel with Janus micromotors embedded was first prepared. Briefly, clay nanosheets (Laponite XLG, BYK Additives & Instruments) were added in deionized water and stirred for 30 min to form an aqueous dispersion (0.5 wt%). Then acrylic acid (AAc, 3.15 wt% of deionized water weight) and acrylamide (AAm) monomers (Shanghai Rich Joint Chemical Reagent Co. Ltd.) with a molar ratio of 0.15, Janus micromotors dispersion (3.2% of total volume of the solution) was added to the above clay dispersion and purged nitrogen gas for 10 min. Subsequently, initiator ammonia persulfate (0.2 wt% of total deionized water weight) and 10 μL accelerator tetramethylethylenediamine (TEMED, J&K Chemical Ltd.) were added. The mixture was rapidly injected into a glass tube with 3 mm in diameter and placed in an oven at 35 ^{o}C for 16 h to form a nanocomposite hydrogel (NC-hydrogel) with Janus micromotors encapsulated. Furthermore, the resulting sample was immersed in a $FeCl_3$ solution (0.06 mol/L) for 3 h and then replaced with deionized water for 12 h to form Janus micromotors embedded DC-hydrogel. DC-hydrogel with 1.0 mm in diameter was fabricated by following the same procedure above.

To fabricate the two-stage rocket with Ag nanoparticles loaded on one side, the Janus micromotors encapsulated DC-hydrogels were cut into several blocks with various lengths, and catalytically active silver particles were decorated on one side of each hydrogel block by silver mirror reaction. 1.0 mL of silver nitrate solution (2 wt%) and 40 μL ammonia (30%) were added into a small petri dish, and gentle shaking was applied to insure the complete dissolution of brown sediments. Then 40 μL of glucose solution (40 wt%) were added into the above solution with hydrogel blocks partially immersed and the petri dish was subjected to constant heating for 5 min at 40^{o}C and the AgNP coating side was dried at room temperature to remove water on surfaces. This resulted in two-stage hydrogel rockets with Ag nanoparticular catalyst loaded on one sides. Hydrogel blocks without Janus micromotor incorporation were also prepared as control samples by following the above similar procedure.

Motion experiment of hydrogel rocket and Janus micromotors. To observe the remote transportation of the two-stage hydrogel rockets, 10% of hydrogen peroxide solution was applied as a driving energy fuel and silicone grease was smeared on the surface of rockets ensuring the rockets drove on the water. The remote transport videos were captured and recorded at ambient temperature using camera. And the propulsion of Janus micromotors was tracked using an inverted optical microscope.

Equipment. Quorum Q150T ES Sputter Coater was utilized to generate the asymmetry Janus micromotors. SEM and EDX (Zeiss VEO 18) characterization was applied to observe the morphology of Janus micromotors, and the distribution of silver nanoparticles on the surface of the hydrogel rockets. Ultraviolet light (wavelength 365 nm, produced by Mercury lamp sockets) was used to control the decomposition rate of the two-stage hydrogel rockets. The trajectory of hydrogel rockets and Janus micromotors were captured and recorded by CANON IXUS 220 HS camera and Zyla scmos digital camera (employing the NIS-Elements AR 4.3 software and 40× objectives).

Extended Figures

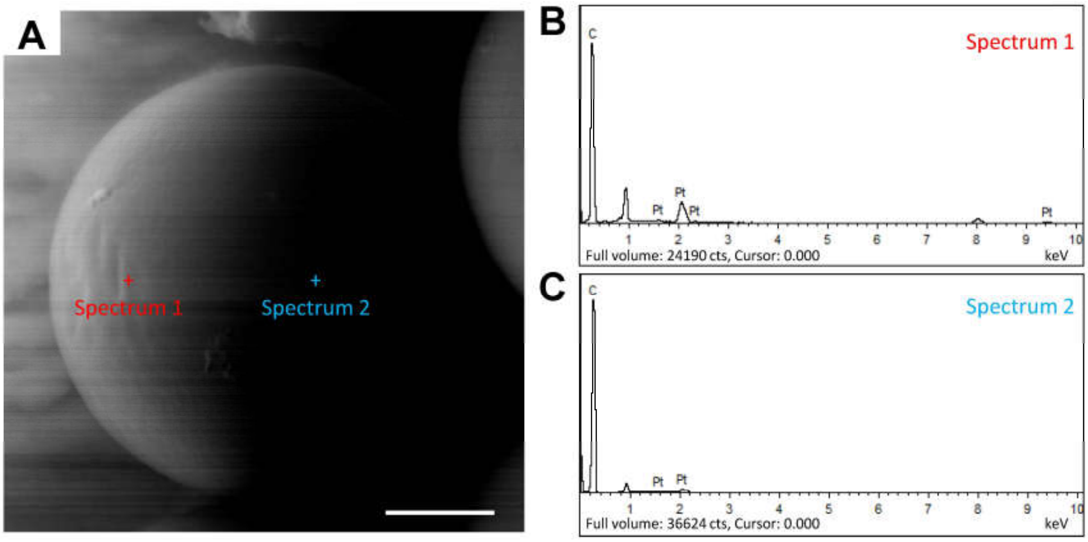

Fig. S1 | (A) The backscattered electron signal image of Janus micromotors. (B) and (C) are the corresponding energy dispersive X-ray (EDX) spectra of the two regions in graph (A), respectively. The scale bar: 2 µm. The EDX spectra indicate the brightness of the backscattered image related to the content of platinum. The brighter regions represent the higher platinum content, which confirms the asymmetric distribution of Pt.

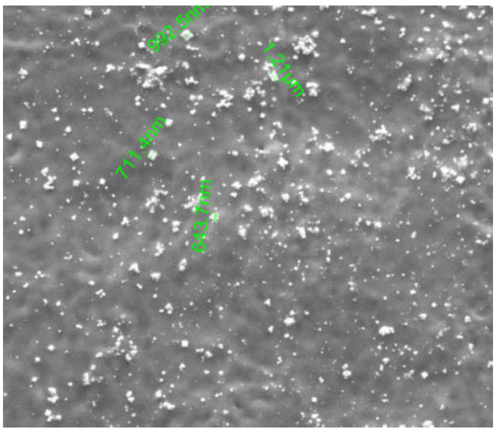

Fig. S2 | AgNPs distributed on hydrogel surface. The diameter of AgNPs is ranged from few nanometers to several hundred nanometers.

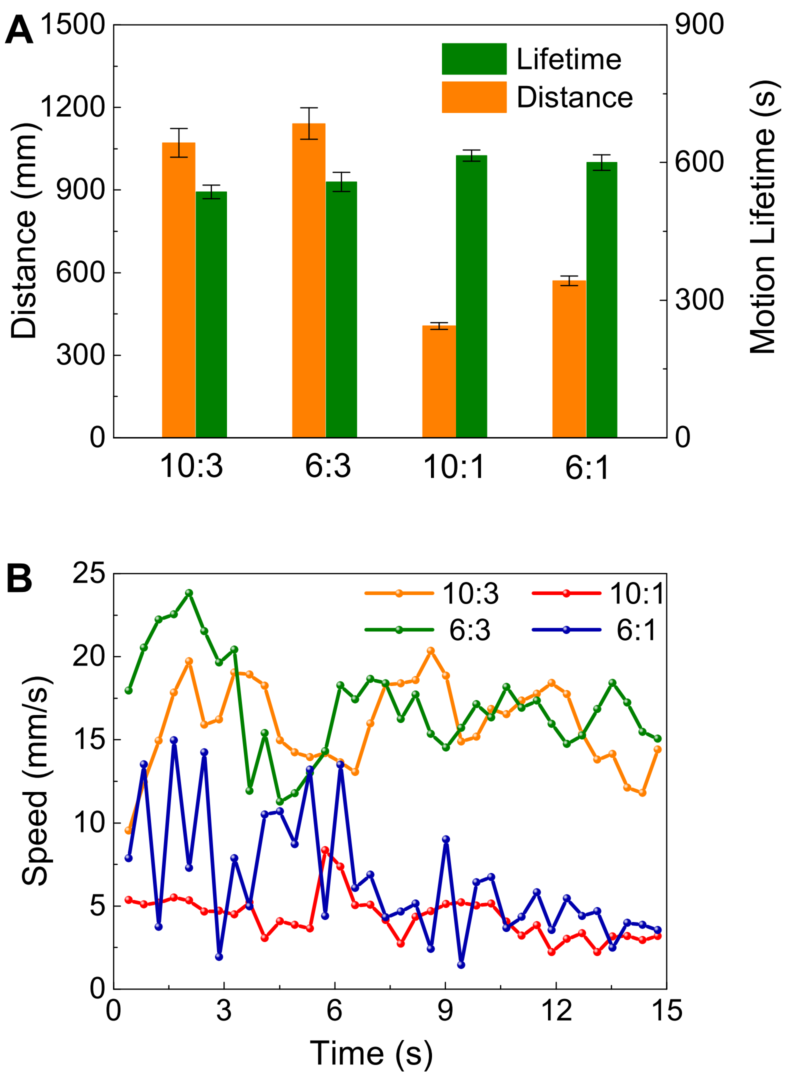

Fig. S3 | (A) The propelling distance and motion lifetime of the two-stage hydrogel rockets with varied lengths and diameters. The former number represents the length value while the later number represents the diameter value, for example, 10:3 is the hydrogel rocket with length of 10 mm and diameter of 3 mm). The concentration of H_2O_2 is 10 wt%. (B) The corresponding speed of various two-stage hydrogel rockets (video 3).

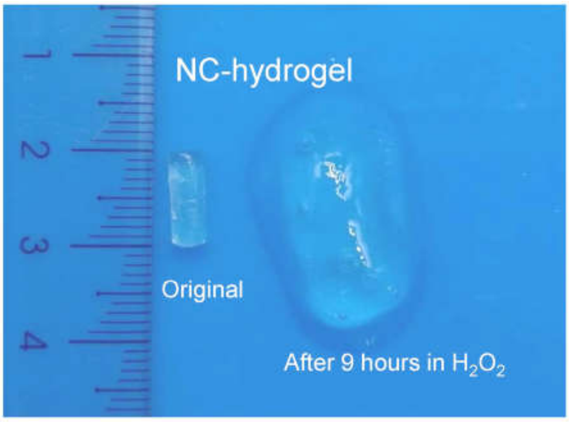

Fig. S4 | The appearance of NC-hydrogel placed in 10% H_2O_2 solution after 9 hours. The NC-hydrogel only swelled in H_2O_2 solution, no hydrogel disintegration can be observed.

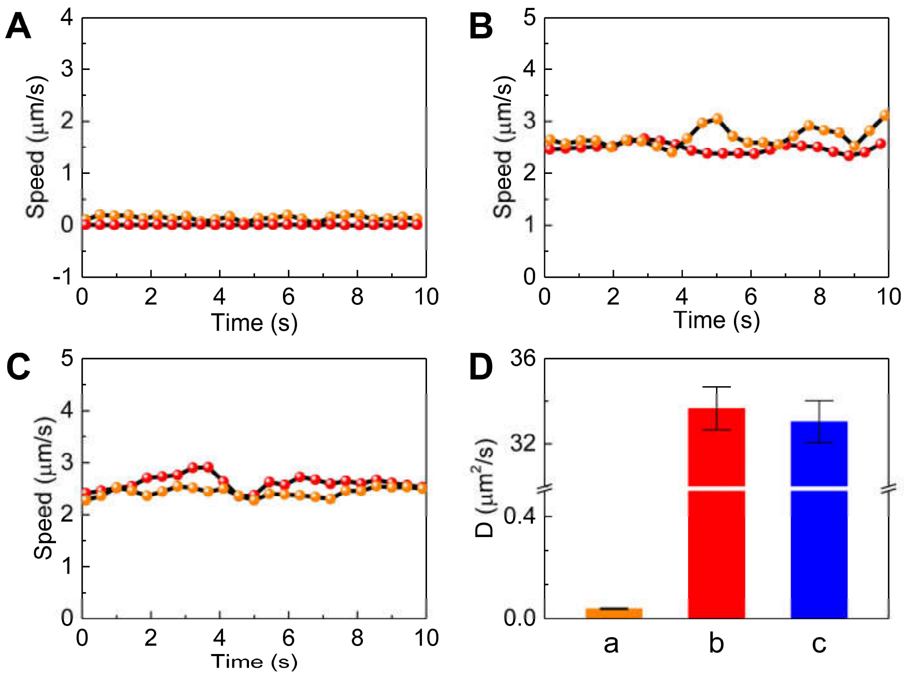

Fig. S5 | The corresponding instantaneous speed and diffusion coefficients of (A) original Janus micromotors in pure water, (B) original Janus micromotors and (C) Janus micromotors released from the two-stage hydrogel rockets in 10% H_2O_2.

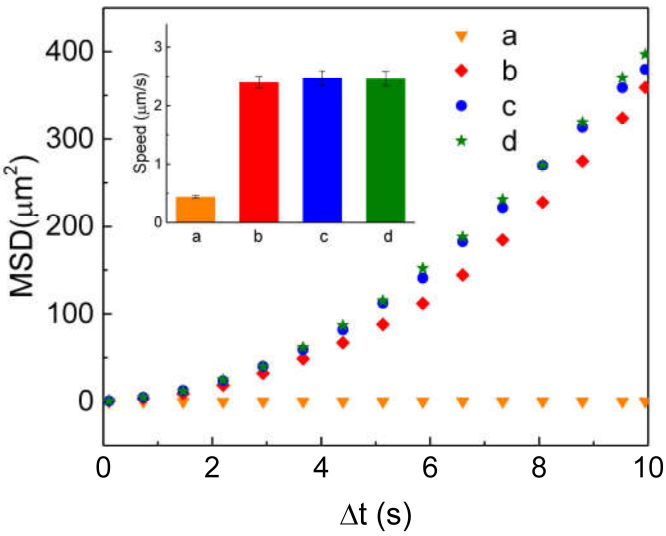

Fig. S6 | The parabolic mean-square displacement (MSD) and speed of different original micromotors in different Fe^{3+} concentration conditions. (a) 17.49 mmol/L (maximum Fe^{3+} concentration may be achieved in the fuel tank after two-stage rocket complete decomposition), without H_2O_2, (b) 17.49 mmol/L (c) 52.47 mmol/L and (d) 104.94 mmol/L in 10% H_2O_2. The ionic strength has little effect on the motion behaviors of Janus micromotors, even in the concentrations higher than the maximum concentration that can be achieved after the completed disintegration of two-stage rocket.