An Ultra-low-frequency, Broadband and Multi-stable Tri-hybrid Energy Harvester for Enabling the Next Generation Sustainable Power

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Introduction

In this work, a highly miniaturized, ultra-low-frequency, broadband, multi-stable, frequency up-converted and tri-hybrid portable energy harvester* is proposed to sustainably power wearable/portable electronics, see Figs. 1–3. This energy harvester is developed using a novel multi-stability based frequency up-conversion (FUC) approach, which is implemented by the highly compact combination of two new configurations of magneto-multi-stable oscillators. Benefiting from the new FUC approach, the harvester can exhibit a quad-stable state in its horizontal direction, this makes the displacement stroke of the low-frequency vibration and the mechanical energy transfer process overlap almost completely. Hence, it can improve the power output and power density under low-frequency, low-intensity, and wideband vibration sources. When operating vertically, the mechanical system of this harvester can degrade into a tri-stable system with a wide band and high efficiency similar to the horizontal state. Moreover, by hybridizing two impact-driven piezoelectric generators (PEG), an array-based electromagnetic generator (EMG), a sliding-type triboelectric nanogenerator and a contact-separation triboelectric nanogenerator (TENG) in a highly compact arrangement, more power can be generated from a single mechanical motion, further improving the power density. Through the theoretical and experimental studies, the mechanical properties and electrical performance of the portable energy harvester are investigated for a low-frequency range, covering general structural/mechanical vibrations and human-induced motions. Under a shaker test, the energy harvester can work well at a frequency range of 1–11 Hz under 1 g (= 9.8 m/s^2) and generate a maximum output of about 86 mW, corresponding to the normalized power density of 3.7 mW cm^{-3} g^{-2} at 3 Hz under 1 g. The present design could realize a wireless power supply to advance the development of current cutting-edge IoT technology for "smart cities", see Fig. 4.

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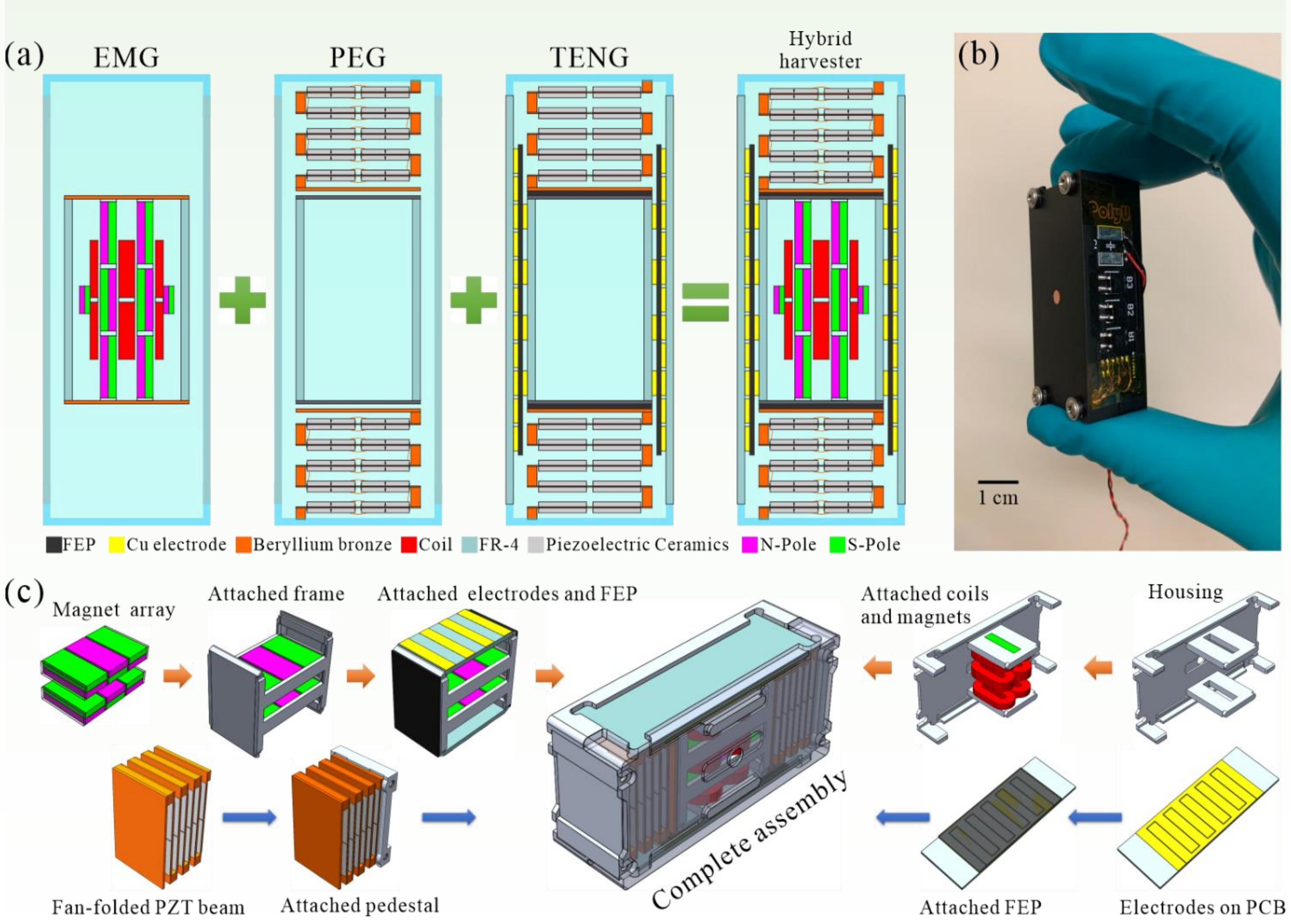

Fig. 1: Schematic of the proposed energy harvester (a tri-hybrid system)

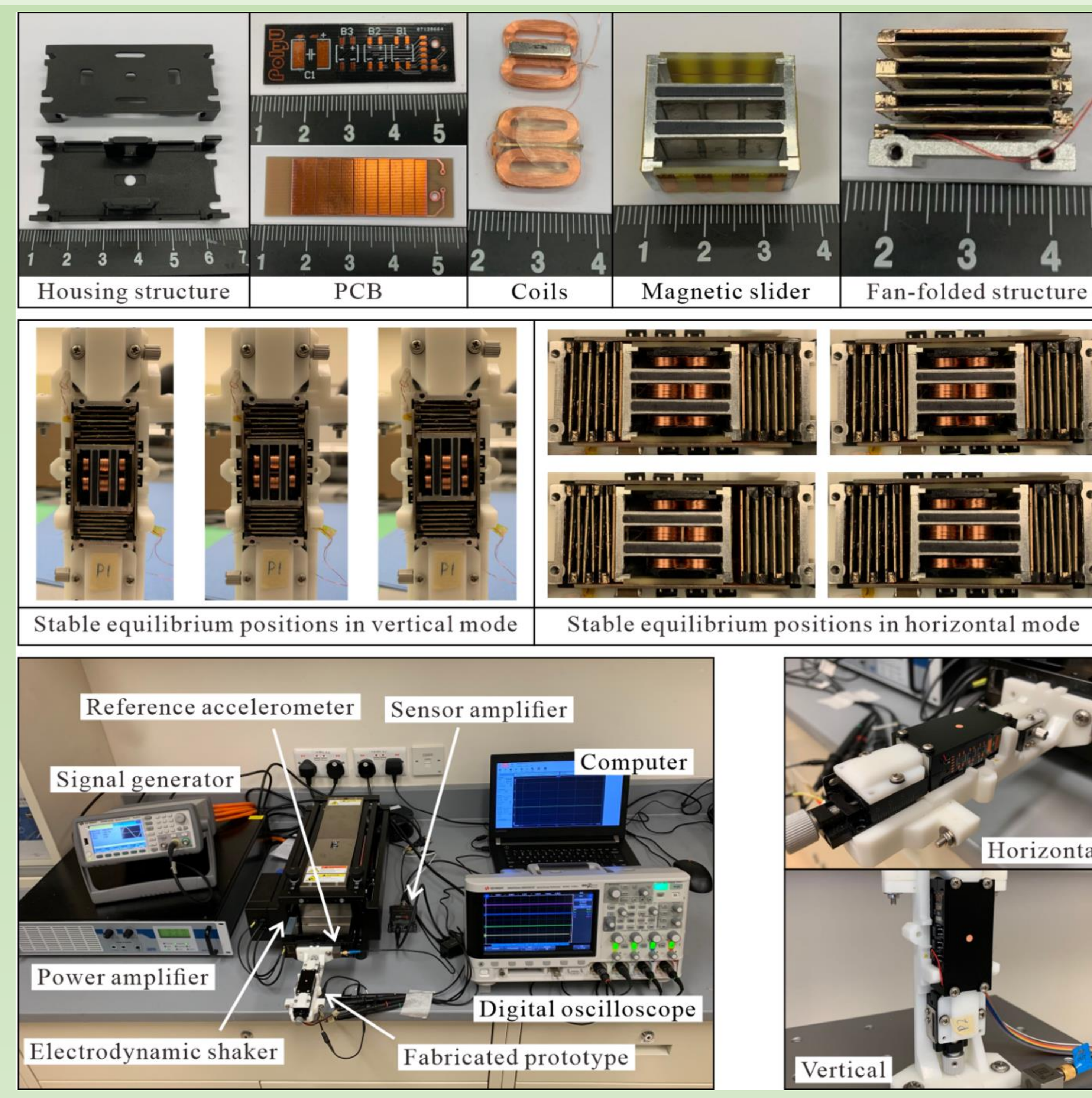

Fig. 2: Fabricated prototype of the proposed energy harvester

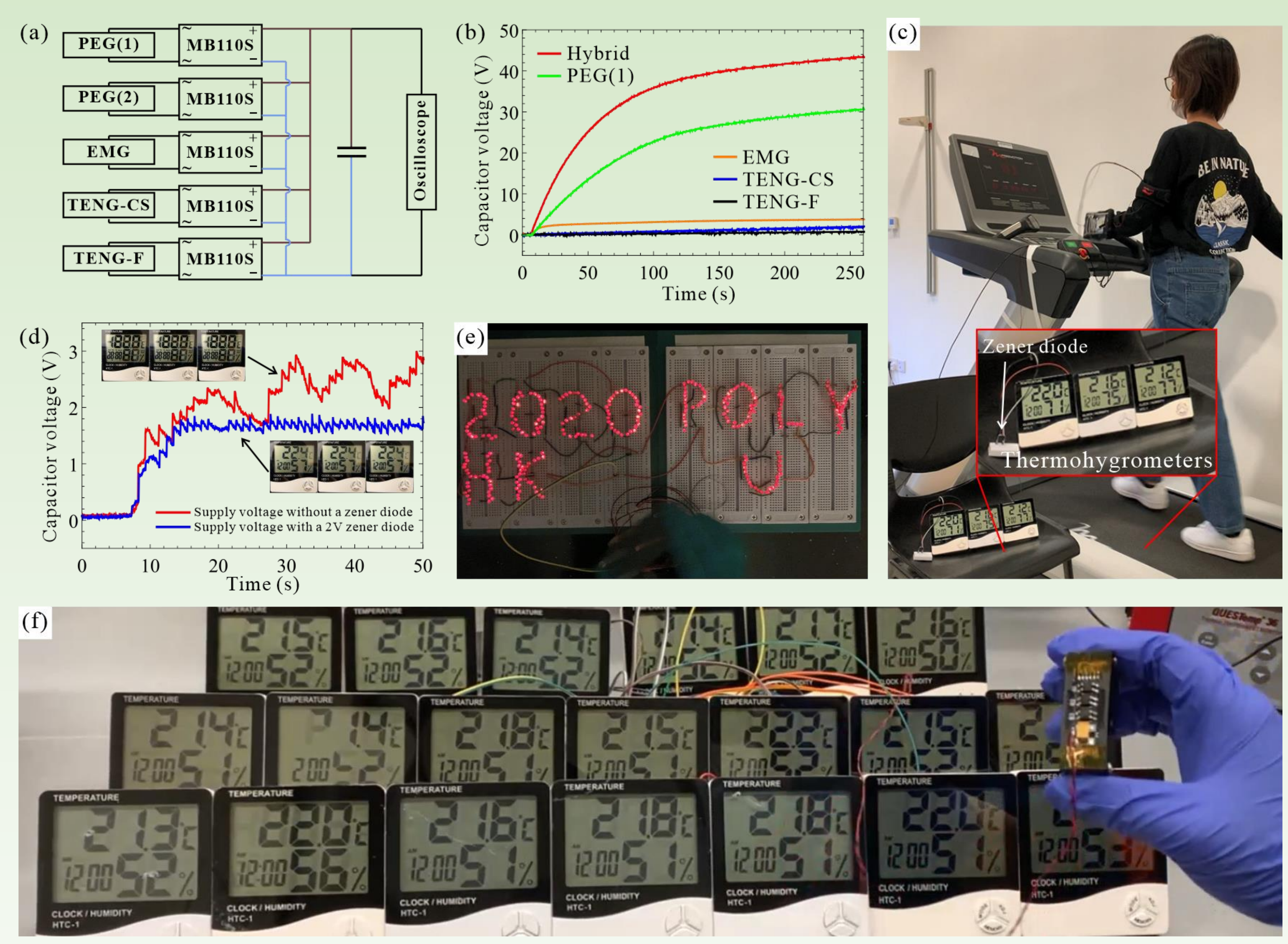

Fig. 3: Working efficiency of the proposed energy harvester on electronics

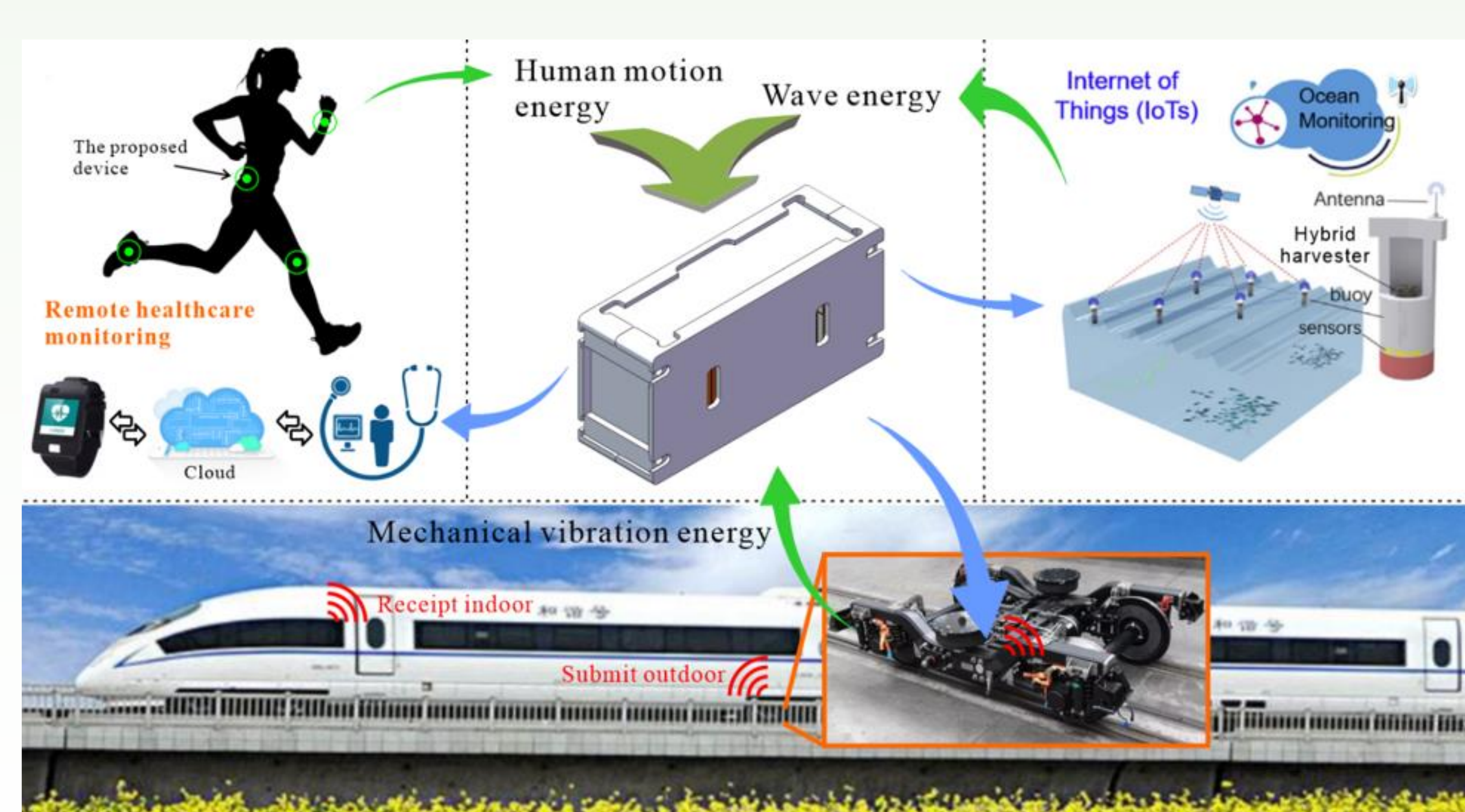

Fig. 4: Potential IoT applications of the proposed energy harvester

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