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Bioinspired engineering

Nature has spent billions of years evolving the most efficient and effective solutions to complex problems, from navigation and energy harvesting to visual processing and biodegradation. Bioinspired engineering draws on these strategies to design adaptive, efficient and sustainable technologies, particularly in fields such as robotics, materials science and medical device engineering.

Biological systems have evolved to adapt and respond to their environment and to navigate and survive in diverse terrain across land, sea and air. Importantly, biological systems typically operate with great energy efficiency, and therefore scientists often turn to nature to solve engineering problems. From air filters modelled on nasal passages[1] and pitcher-plant-inspired sweat monitoring devices[2] to neuromorphic hardware[3], bioinspired designs offer practical solutions across a range of disciplines, including medical device design, computing and manufacturing.

The need for bioinspired design is especially prevalent in robotics. Robots are increasingly used for applications in search and rescue, biological monitoring, agriculture and planetary exploration, in which complex and dynamic environments challenge a robot's agility and navigation. However, robots typically have difficulty transversing uneven or unstable terrain, and even the most efficient bipedal robots fall behind humans in terms of energy usage. In a Review in this issue, Barbara Mazzolai and team analyse the cost of transport for different animals, plants and robotic systems to identify energy-efficient movement strategies that can inform robot design.

Energy expenditure during movement depends not only on the energy taken to complete an action but also on a 'pre-investment' – in a biological system, this is the cost of building tissues for specialized processes. Similarly, energy-efficient robots can be designed for specific environmental conditions. For example, aerial robots can be engineered to harness wind currents similarly to gliding birds, and underwater robots can use octopus-inspired jet propulsion to move. Along with agility, bioinspired designs can enhance a robot's ability to explore by improving responsiveness to environmental cues and navigation strategies. Animals have evolved integrated multisensory systems, such as visual, magnetoreception and distance sensing, that enable them to navigate difficult terrain and long migration paths. In a Comment in this issue, Weimin Zhang and colleagues outline the design of robots that mimic these behaviours by integrating multiple sensors and using neuromorphic chips or algorithms trained on animal patterns to process sensory information for efficient navigation.

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Biological energy-processing solutions can also inform the design of materials for solar energy conversion. Photosynthetic organisms, in particular, have evolved highly efficient electron transport chains that convert solar energy into chemical energy. These pathways can be re-engineered to drive new, non-natural processes in rewired photosynthetic systems, which offers a versatile, sustainable and long-lasting approach to green solar technologies[4].

The principles of bioinspired design also extend to artificial vision. In a Review in this issue, Yang Chai and colleagues explore technologies that mimic the structure and function of biological eyes, by leveraging adaptive optics and in-sensor computing for visual processing. Alternatively, bioinspired optical and optoelectronic implants can restore or replace eye components.

Beyond specific applications, bioinspired design can shape the entire life cycle of artificial systems. Similar to living organisms, artificial systems could be designed to grow, adapt and safely degrade after they have outlived their functional capacity[5]. For medical applications, microrobots or implanted materials that degrade in the body after use can eliminate the need for surgical removal and prevent complications. In remote or low-resource settings, energy-efficient design can extend a device's functionality, and recyclability or biodegradability could extend the usefulness beyond functionality – or at least prevent it from becoming litter. Therefore, a bioinspired framework can pave the way for more adaptive, efficient and environmentally responsible artificial systems.

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