Bio-Inspired Engineering of Exploration Systems

Exploration systems with capabilities imbibed from nature enable new operations that were otherwise very difficult or impossible to accomplish.
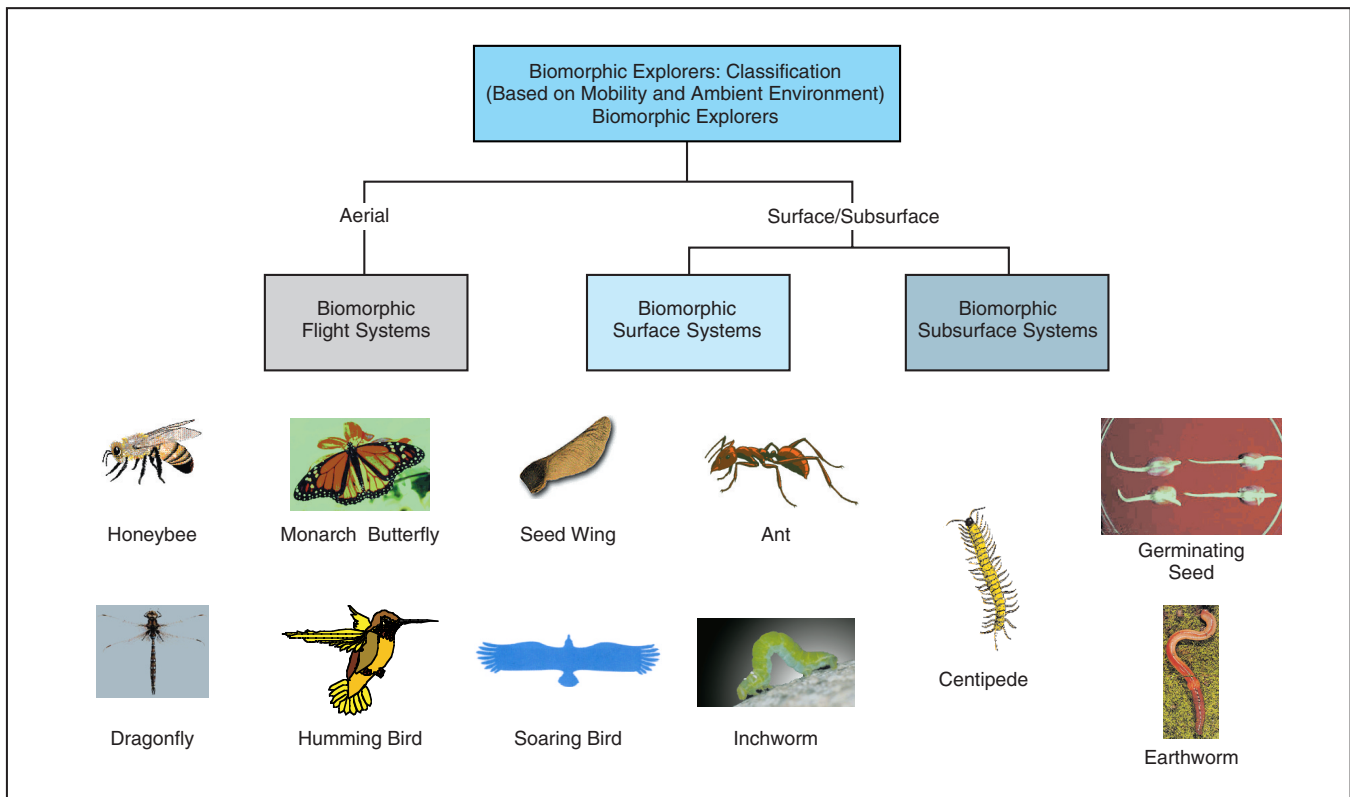
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The multidisciplinary concept of "bioinspired engineering of exploration systems" (BEES) is described, which is a guiding principle of the continuing effort to develop biomorphic explorers as reported in a number of articles in the past issues of *NASA Tech Briefs*. The intent of BEES is to distill from the principles found in successful nature-tested mechanisms of specific "crucial functions" that are hard to accomplish by conventional methods but that are accomplished rather deftly in nature by biological organisms. The intent is not just to mimic operational mechanisms found in a specific biological organism but to imbibe the salient principles from a variety of diverse bio-organisms for the desired "crucial function." Thereby, we can build explorer systems that have specific capabilities endowed beyond nature, as they will possess a combination of the best nature-tested mechanisms for that particular function. The approach consists of selecting a crucial function, for example, flight or some selected aspects of flight, and develop an explorer that combines the principles of those specific attributes as seen in diverse flying species into one artificial entity. This will allow going beyond biology and achieving unprecedented capability and adaptability needed in encountering and exploring what is as yet unknown. A classification of biomorphic flyers into two main classes of surface and aerial explorers is illustrated in the figure, with examples of a variety of biological organisms that provide the inspiration in each respective subclass.

Such biomorphic explorers may possess varied mobility modes: surface-roving, burrowing, hopping, hovering, or flying, to accomplish surface, subsurface, and aerial exploration. Preprogrammed for a specific function, they could serve as one-way communicating beacons, spread over the exploration site, autonomously looking for/at the targets of interest. In a hierarchical organization, these biomorphic explorers would report to the next level of exploration mode (say, a large conventional lander/rover) in the vicinity. A widespread and affordable exploration of new/hazardous sites at lower cost and risk would thus become possible by utilizing a faster aerial flyer to cover long ranges and deploying a variety of function-specific, smaller biomorphic explorers for distributed sensing and local sample acquisition. Several conceptual biomorphic missions for plane-

These **Examples of Biological Inspirations** show different mobility categories.

tary and terrestrial exploration applications have been illustrated in "Surface-Launched Explorers for Reconnaissance/Scouting" (NPO-20871), *NASA Tech Briefs*, Vol. 26, No. 4 (April, 2002), page 69 and "Bio-Inspired Engineering of Exploration Systems," *Journal of Space Mission Architecture*, Issue 2, Fall 2000, pages 49-79.

Insects (for example, honey bees and dragonflies) cope remarkably well with their world, despite possessing a brain that carries less than 0.01 percent as many neurons as that of the human. Although most insects have immobile eyes, fixed-focus optics, and lack stereo vision, they use a number of ingenious strategies for perceiving their world in three dimensions and navigating successfully in it. We are distilling some of these insect-inspired strategies to obtain unique solutions to navigation, hazard avoidance, terrain following, and smooth deployment of payload. Such functionality can enable one to reach previously unreachable exploration sites.

In-situ, autonomous exploration and science return from planetary surfaces and subsurfaces would be substantially enhanced if a large number of small, inexpensive, and therefore dispensable, biomorphic explorers equipped with dedicated microsensors could be spread over the surface. Their low-cost and small size would make them ideal for hazardous or difficult site exploration, inspection, and testing. Their dedicated sensing functions and autonomous maneuverability would be valuable in scouting missions and sample acquisition from hard-to-reach places. As was mentioned earlier, when preprogrammed for a specific function and spread over the exploration site, these explorers could serve as intelligent, downlink-only beacons that autonomously look for objects of interest. Alternatively, these biomorphic explorers can operate in a hierarchical organization and report their findings to the next higher level of exploration (say, a large conventional lander/rover) in the vicinity. Specifically, our recent results demonstrate the novelty of our approach in adapting principles proven successful in nature to achieve stable flight control, navigation, and visual search/recognition. This approach has enabled overall a robust architecture for reliable image data return in application scenarios both for terrestrial and planetary needs where only a limited telecommunications or navigational infrastructure is available and is therefore otherwise by traditional methods hard or impossible to explore.