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Exploring the Use of Functional Models in Biomimetic Conceptual Design

The biological world provides numerous cases for analogy and inspiration. From simple cases such as hook and latch attachments to articulated-wing flying vehicles, nature provides many sources for ideas. Though biological systems provide a wealth of elegant and ingenious approaches to problem solving, there are challenges that prevent designers from leveraging the full insight of the biological world into the designed world. This paper describes how those challenges can be overcome through functional analogy. Through the creation of a function-based repository, designers can find biomimetic solutions by searching the function for which a solution is needed. A biomimetic function-based repository enables learning, practicing, and researching designers to fully leverage the elegance and insight of the biological world. In this paper, we present the initial efforts of functional modeling biological systems and then transferring the principles of the biological system to an engineered system. Four case studies are presented in this paper. These case studies include a biological solution to a problem found in nature and engineered solutions corresponding to the high-level functionality of the biological solution, i.e., a housefly's winged flight and a flapping wing aircraft. The case studies show that unique creative engineered solutions can be generated through functional analogy with nature. [DOI: 10.1115/1.2992062]

1 Introduction

The designs of the biological world allow organisms to survive in nearly all of earth's challenging environments filling niches from under-sea volcanic vents, tundras both frozen and desolate, poisonous salt flats, and deserts rarely seeing rain. Nature's designs are the most elegant, innovative, and robust solution principles and strategies allowing for life to survive many of the earth's challenges. Biomimetic design aims to leverage the insight of the biological world into the engineered world, but because of numerous challenges, biomimetic design is still undeveloped as a method for formal concept generation. Allowing design engineers' formal and full access to the solution principles and strategies of the biological world remains beyond current methods and knowledge.

Many challenges prevent immediate adoption of designing via biological inspiration including (1) a lack of equivalent engineering technologies, (2) a knowledge gap between designers and biologists, and (3) unawareness of analogous biological systems. Significant effort and time are required to become a competent engineering designer, which creates an equally significant obstacle to becoming sufficiently knowledgeable about biological systems to effectively execute biomimetic design. Formal design based on functional modeling and concept generation methods [1–9] provides a unique opportunity to extend biomimetic design to meet the challenges thwarting the adoption into formal engineering design practices. The generation of functional models based on *what* a product must do instead of *how* it will be accomplished provides designers with many benefits such as explicit correlation with customer needs, comprehensive understanding of the design problem, enhanced creativity through abstraction, and innovative concept generation focused on answering what must be done [7,8]. Design based on functional modeling provides designers with the freedom to consider the functionality of analogous biological systems without the burden of technological feasibility, and when applied with automated concept generation techniques based on predefined and expandable knowledge bases such as a design repository, biological systems may be explored without the need for advanced training in biological sciences.

The representation of products by function has enabled the creation of design repositories allowing designers to access solution principles that are outside their personal knowledge or expertise [10–13]. The ability of functional representation to allow designers to access such design information is a key impetus toward the extension of biomimetic design through the method of functional modeling. If biological inspiration requires designers to have extensive knowledge of biological systems, then the insight of the biological world will never be fully accessible to engineering design. The objectives of the research presented in this paper are to functionally explore biological systems to discover the knowledge needed to enable a function-based biomimetic design repository. First, a brief summary of previous work in biomimetic design is provided. Next, the research methodology that was followed to generate the case studies found in Sec. 4 of this paper is discussed. Finally, conclusions reached thus far in this research are discussed as well as a summary of the direction for future work to be completed.

2 Background and Related Work

Numerous biomimetic designs have been developed, where in most cases, the engineered system is a direct emulation of the biological system. For example, prosthetic replacements are a biomimetic design mimicking bone structure. Novel and nonobvious solutions, however, may require the biological system be viewed from a different perspective than an attempt to directly copy nature. The main focus of this research is to provide engineers with a method of learning enough about biological phenomena to inspire novel designs. For example, while plants may be stationary,

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