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Biologically Meaningful Keywords for Functional Terms of the Functional Basis

Biology is recognized as an excellent source of analogies and stimuli for engineering design. Previous work focused on the systematic identification of relevant biological analogies by searching for instances of functional keywords in biological information in natural-language format. This past work revealed that engineering keywords could not always be used to identify the most relevant biological analogies as the vocabularies between biology and engineering are sufficiently distinct. Therefore, a retrieval algorithm was developed to identify potential biologically meaningful keywords that are more effective in searching biological text than corresponding engineering keywords. In our current work, we applied and refined the retrieval algorithm to translate functional terms of the functional basis into biologically meaningful keywords. The functional basis is widely accepted as a standardized representation of engineering product functionality. Therefore, our keywords could serve as a thesaurus for engineers to find biological analogies relevant to their design problems. We also describe specific semantic relationships that can be used to identify biologically meaningful keywords in excerpts describing biological phenomena. These semantic relations were applied as criteria to identify the most useful biologically meaningful keywords. Through a preliminary validation experiment, we observed that different translators were able to apply the criteria to identify biologically meaningful keywords with a high degree of agreement to those identified by the authors. In addition, we describe how fourth-year undergraduate mechanical engineering students used the biologically meaningful keywords to develop concepts for their design projects. [DOI: 10.1115/1.4003249]

1 Introduction

Biomimetic design uses biological phenomena as inspiration to solve engineering problems. Humans have borrowed many ideas from biology for design. Although many examples of successful biomimetic design exist, most of them were inspired from chance observation. As such, the potential of using biological phenomena to create innovative designs may be limited by an engineer's existing or chance biological knowledge. Therefore, engineers may benefit from a systematic method that helps them access the vast amount of biological information in existence, which may lead to more novel and useful concepts.

Our approach has focused on directly searching biological information that is already available in natural-language format, e.g., texts, papers, etc. However, past work revealed that this approach may be limited by differences in lexicons, or vocabularies, between the domains of engineering and biology, i.e., words widely used in engineering might be used in different meanings or uncommonly in biology and vice versa [1]. Hon and Zeiner [2] supported that product design information retrieval is challenging because different words could describe the same functions. Chiu and Shu [3] therefore developed an algorithm to identify potential biologically meaningful keywords that can locate biological analogies, which may not be otherwise found if the engineering keywords describing the problem were used for the search instead.

This retrieval algorithm is adapted and refined here to generate biologically meaningful keywords that correspond to functional terms of the functional basis developed by Stone and Wood [4]. The functional basis has been widely accepted as a standardized set of engineering terms used for functional modeling. We believe that this translation is a significant step toward allowing engineers better access to biological analogies for design. Once engineers functionally model a desired product, they can look up the corresponding biologically meaningful keywords and use them to search for relevant biological analogies.

The functional basis consists of generic taxonomies of engineering functions, defined as function sets, and associated flows to describe product functionality [5]. Function sets are represented by verbs, and flows are represented by nouns. In this work, we translated the function sets to obtain biologically meaningful keywords that are verbs as well. Using verbs to serve as biologically meaningful keywords enables engineers to explore various biological phenomena related to the verb function, rather than focusing on a particular biological phenomenon associated with a noun [6,7]. For example, for the engineering function "protect," searching with the keyword verb "cover" will locate various phenomena related to covering and protecting. However, searching for the biological noun "cuticle" will only result in information related to cuticles. A cuticle is the thin outermost noncellular layer covering parts of plants and invertebrates and is only one means in biology to enable covering and protection.

This paper presents how biologically meaningful keywords for the function sets of the functional basis were systematically identified. First, we present nomenclature used in this paper before discussing relevant work and describing the retrieval algorithm. Next, we present identification criteria for selecting the most useful biologically meaningful keywords and discuss how these new keywords usually form specific semantic relations with the original functional keywords. We then present a set of biologically meaningful keywords that correspond to function sets of the functional basis, discuss preliminary assessments of the identification criteria, and provide examples of how fourth-year undergraduate mechanical engineering students successfully used some of the

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