Bioanalogous Mechanical Joints for Authorized Disassembly

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Abstract
This paper describes bioanalogous, or biomimetic, lock-and-key mechanical joints that enable disassembly that is easy but only by those authorized. The problem is motivated by the increasing need for economical disassembly of products by original equipment manufacturers (OEMs) while protecting high-value components from theft and third-party recyclers. The joints must be easy to disengage with the 'key' but difficult to disengage without it. They also must be easy to manufacture, assemble and provide sufficient stiffness. An analogous biological phenomenon involving enzyme-substrate interaction was used to inspire the development of a heat-reversible snap-locator joint system.

Keywords:
Disassembly, Joining, Biologically inspired design

1 INTRODUCTION

Recent legislative and social pressures have driven product manufacturers to reduce the amount of material that enter the waste stream at product retirement. For example, in the European Union, the WEEE (Waste Electrical and Electronic Equipment) directive mandates minimum reuse/recycle proportions of retired consumer electrical appliances for their manufacturers. Therefore, products are designed with increased emphasis on effective reuse and recycling at the end of product life. Since both part reuse and material recycling require the disassembly of products, Design for Disassembly (DFD) has become a key design strategy for product manufacturers.

Despite the possibility of incurring additional costs during design and manufacturing, pursuing the ease of product disassembly can benefit manufacturers by reducing disassembly cost and thus increasing the net profit from reuse and recycling. To sustain reuse/recycle infrastructures, it is crucial that OEMs can retrieve easily parts with high reuse/recycle values. Such high-valued parts, however, would also attract third-party entities, authorized or not, to start reuse and recycling operations independent of OEMs. For example, if a product contains relatively new microchips and memory components, or large amounts of indium, platinum, and gold, the value of these parts and materials can well offset the cost of independent collection, disassembly, refurbishing, shredding and sorting, and purifying and processing. Such third-party operations would be the unintended beneficiaries of additional OEM investment during design and manufacture to enable the ease of product disassembly. To discourage such third-party activities, OEMs may desire high-valued components to be very difficult to retrieve without authorized means (e.g., a disassembly 'key').

This paper describes the biomimetic, or bioanalogous, design [1,2] of 'lock and key' mechanical joints that enable disassembly that is easy but only by those authorized. Relevant biological phenomena identified using keyword searches are summarized, followed by the description of a heat-reversible snap-locator system concept that was inspired by biological phenomena.

2 RELATED AND PREVIOUS WORK

2.1 Related work

Design for disassembly encompasses design methods and guidelines that enhance the ease of disassembly for product maintenance and/or end-of-life (EOL) treatments such as recycling and reuse [3-6]. As is the case in design for assembly, the estimation of disassembly difficulty has been a focus of DFD research [7,8], since it is a major driver of disassembly cost [9]. Desai et al. [10] developed a scoring system that considers factors associated with disassembly time such as disassembly force, the requirement of tools and the accessibility of fasteners. Sodhi et al. [11] focused on the effect of unfastening actions on disassembly cost and constructed a 'U-effort' model that helps designers select fasteners for easy disassembly. Perhaps most related to the present work is the concept of active disassembly using smart materials (ADSM) that relies on self-disengaging fasteners and compression springs by Chiodo et al. [12]. Although effective in the specific cases presented, the concept may have shortcomings in general applications, as it requires the use of special and costly materials.

2.2 Previous Work

A biomimetic design method was developed that identifies biological phenomena relevant to engineering problems by conducting keyword searches on natural-language biological text. Previous applications include those in design for remanufacture [1] and microassembly [2]. A simple keyword search on electronic text, with no special indexing/clustering of the contents, is employed since the purpose is to inspire, not to provide solutions to given engineering problems. For example, the keyword 'center' was searched in an introductory biology text [13], which led to the development of concepts for centering microscale objects during assembly [2].

3 BIOMIMETIC 'LOCK-AND-KEY' CONCEPT

3.1 Problem Statement

Mechanical joints are required that enable disassembly that is easy but only by those authorized (i.e., OEMs and