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# Feasibility study on self-healing compliant actuators

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***Abstract*—Natural organisms have a unique property not yet available in robotics, a self-healing (SH) ability. This powerful biological healing function has inspired chemists to impart similar properties to synthetic materials to create "self-healing materials". Recent development in SH-polymers made us investigate the potential of using these materials in robotics, and more specifically in compliant actuator.**

***Index Terms*—Self-healing material, Diels-Alder polymers, Compliant Actuators, Robotics**

## I. Motivation

In the last 15 years [1] a broad range of SH-materials has been studied and although SH-concepts are currently used in some commercial applications (e.g. the SH-paints of Nissan and AkzoNobel), the SH-technology is not yet exploited in robotics. Most developed applications are SH-coatings [1], [2] which can be easily applied on future robotic skeletons and covers, permitting the healing of scratches. Recently a stretchable SH-film [3] was developed having a large potential for artificial skin applications in robotics. This work concentrates on SH-systems dealing with damages due to the overload of robotic joints and with large macroscopic perforations and cracks due to sharp objects. Therefor, the focus is on the introduction of a SH-concept in actuators.

Compliant actuators are increasingly used to reach energy efficiency and safety during interaction with humans or unstructured, dynamic environments. As robots are finding more and more applications in these environments and as these actuators resemble more closely to biological muscle systems, the SH-implementation was done in compliant actuators.

In order to be able to withstand unexpected loads, these actuators are over-dimensioned, such that they can withstand extreme circumstances, avoiding any damage. Hence, the robots are dimensioned based on extreme loads, taking in account a high safety factor, instead of on their performance tasks, resulting in heavy weight, over-sized robotic systems. Based on the SH-property of organisms, the implementation of SH-materials in actuator designs will lead to a reduction of the over-dimensioning and eventually to lighter, more efficient designs. In general, the compliant elements used in compliant actuators are susceptible to damage by sharp objects found in unstructured environments, a problem which can be solved by constructing the compliant elements out of SH-materials. In addition, self-healing will have a beneficial impact on sustainable manufacturing, since the life span of components can be drastically increased.

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## II. Feasibility study

Through prototyping, a feasibility study was conducted, in which two compliant actuator types were investigated, focusing on the implementation of a SH-mechanism. The results are published in two recently submitted papers [4], [5]. The self-healing of both actuator types relies on dynamic covalent polymer network systems based on the reversible Diels-Alder (DA) reaction [2]. Macroscopic damages in these non-autonomous DA-polymers can be healed in a couple of hours using relatively low temperatures (70-130 °C).

Firstly, a self-healing mechanical fuse was developed [4], which can be inserted in a series elastic actuator. Whenever a damaging overload, which could potentially damage one of the actuator components, occurs on the system, the fuse fractures sacrificially and can be self-healed afterwards. Using this principle all components are protected and there is no need for large over-dimensioning.

Secondly, to evaluate the potential of creating a soft pneumatic actuator (SPA) entirely out of SH-polymer material, a single soft pneumatic cell was build entirely out of the DA-polymers [5]. From this single-cell prototype it is straight-forward to build the first SH-multi-cell SPA, one that can self-heal damages caused by sharp objects.

For both prototypes, the mechanical properties of the actuator were recovered after the complete healing of macroscopic damages, proving the potential for further investigation on the use of DA-polymers and other SH-polymers in robotic actuator applications.

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