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Soft Robotics: Resilient Intelligent Machines through Morphological Changes

Helmut Hauser[1,2], [1]Department of Engineering Mathematics, University of Bristol, Woodland Road, BS8 1UB, UK, [2]Softlab, Bristol Robotics Laboratory, Bristol, UK
helmut.hauser@bristol.ac.uk

To prepare robots for working autonomously under real-world conditions, their resilience and capability to recover from damage needs to improve radically. A fresh take on robot design suggests that instead of adapting the robotic control strategy, we could enable robots to change their physical bodies to recover more effectively from damage.

Despite the success story of industrial robotics, so far, the research community has not been able to fully translate these achievements into truly autonomous robots working in open world scenarios. A recently published work by Kriegman et al. (1) suggests a key to this problem might be to allow them to adapt their physical bodies.

From the perspective of designing intelligent systems that are meant to work outside the predictable environment of a factory floor, the world is uncertain, dynamic and noisy and, consequently, hard to model and control. Accidents and damages like a loss of a limb or sensor failure can be expected to be quite common. This requires a level of robustness and resilience that still has to be mastered in artificial systems. Current robots simply cease to work in such a situation without human intervention, as they do not have the tools to recover themselves.

Previous work suggested purely algorithmic approaches to deal with damage by providing an alternative control strategy for the impaired body (2,3). While impressive, found solutions are still poor compared to the resilience that can be observed in biological systems. Kriegman et al. presented an alternative approach showing that recovery from damage could be significantly improved by allowing the body to adapt instead of the controller. They simulated a robot based on soft cuboids which was tasked with locomotion. The control strategy was based on a central, periodic signal which was applied to each cuboid individually by using different, optimized, phase shifts. This resulted in a coordinated, periodic inflation/deflation all over the body leading to locomotion. To investigate damage recovery strategies, they started with a robot consisting of a rectangular block with four, attached legs (see figure). With the help of evolutionary algorithms, a control strategy (i.e., which cuboid has which individual phase shift relative to the central control signal) was optimized to make the robot locomote as far as possible within a given time window.

After this initial optimization the robot was damaged to different degrees ranging from simply removing a leg, to cut-off all legs, to halving the robot. Even the case where 3/4 of the robots were removed was considered. Two recovery strategies using evolutionary algorithms were compared, i.e., (i) re-optimizing the controller and, (ii) changing the morphology using the existing controller. Interestingly, adapting the morphology (i.e. shifting the offset/resting position for individual blocks for the inflation/deflation oscillation) instead of the controller lead to better results in all damage cases. In some of them the difference was significant.

Moreover, remarkably, morphological adaptations lead in a few cases to solutions that outperformed the original and optimized robot. This points to the fact that considering the body as part of the design process is crucial. A wrong choice of body morphology can lead to a decreased performance even with an optimal control strategy. This has been pointed out previously and is typically referred to embodied intelligence or morphological computation (4,5).

A limitation of Kriegman et al.'s approach is the use of genetic algorithms. While this is useful in simulations, in physical implementations this is typically not feasible due to time constraints. Therefore, there is still a need to find decentralized, relatively fast optimization techniques that can work online. For example, variations of the approach suggested by Hermans et al. might be applicable (6).

Kriegman et al. were also able to observe that the adaptation of the controller often lead to similar strategies, while changing the morphology resulted in a variety of rather creative solutions. In one particular case, morphological changes let the robot flip over to improve locomotion. This is also consistent with previous work that shows including morphological parameters to optimize control can lead to a surprisingly rich set of behaviors in even simple systems (7).

Kriegman et al.'s results were obtained through simulations. While they haven't translated their approach to a fully functioning robot, they were able to show that in principle such systems could be built using technologies from soft robotics (8).Their approach to use soft cuboids to construct robots is tightly connected to their simulation environment and might not be the best approach to build such systems. However, there is a lot of potential in using the ever growing tool box of smart material (9) to build stimulation-driven structures.

Moreover, we can go beyond simple, constrained morphological changes. Intelligent machines can be equipped with artificial growing mechanisms and therefore enabling them to tackle uncertainties and damages with a much richer set of possible strategies. This is especially relevant when we consider that biological systems outperform state-of-the-art robots in almost any task. This superiority is tightly connected to the capability of growing and therefore to radically change the body. We can see that in plants (e.g., bonsais which recover from extreme damage), in animals (e.g., four-legged animals learn to walk on two after accidents by changing their muscular and bone structures), to organisms that can completely rebuild their bodies based on a small piece of themselves (e.g. the planarian flatworm).

The results by Kriegman et al. remind us that the way we build intelligent machines might have to be reconsidered. To decades-old approach to assemble rigid links with high-torque servo motors might be a good approach to build machines for specific tasks and simplified environments, but they constrain us in building intelligent systems that should work in the open world where robustness and resilience is needed.

Competing Interests

The author declares no competing interests.

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