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Hybrid Soft/rigid Robots for medical applications

François Schmitt¹, Olivier Piccin², Laurent Barbé¹ and Bernard Bayle¹

The late twentieth century has seen the development of robotic systems that are ever more accurate, powerful, rigid... Those developments allowed them to complement the work-force in industrial environments, but also to help physicians in the medical field with a wide range of application, from surgical assisting tools [1], [2], positioning tools [3], [4] to active instruments [5]. However, while those rigid robots are very effective in fully constrained environments or as slaves where humans have an active role in the loop, they lack the ability to interact with complex and unconstrained environments without requiring a constant supervision.

In parallel, the 90's have seen new robotic concept appear, initially taking inspiration from biological structures where rigid elements are not as predominant as they are in classical robotics [6]. Those soft robots take advantage from their low stiffness to create motions with large amplitude. They can also react to unplanned interaction with environment of various nature thanks to their high compliance and their ability to "morphologically compute" those interactions [7]. Although usually more complex to model and thus less precise than their rigid counterparts, those concept are usually simpler to use and adapt to medical applications requiring adaptability, such as active orthosis [8], [9], [10], for the assistance or replacement of physiological structures [11], [12], or also to help the exploration of internal cavities [13], [14].

Some more complex tasks may however benefit from both worlds, chiefly for medical applications. Indeed, a robot may need, for example, accurate positioning while ensuring the safety of patients and medical staff by reducing the interaction forces. Those problems can be solved by combining features from both soft and rigid robots.

I. HYBRID SOFT/RIGID ROBOTS

By hybrid soft/rigid robots (HSR) [15], [16], we define robots that combine elements that are either soft, rigid or both, in any fashion. Typical example would be the introduction of flexible elements in a rigid transmission chain, as we could found in the series elastic actuators [17]. The robots based on this kind of actuators can not be considered as soft robot or hybrid, but they were the first step to increase flexibility with respect to classical robots, allowing them to carry several types of task: low-pass filtering of shocks, improved interaction control with unexpected environment, and energy storage and restitution similarly to what can be seen in animal locomotion.

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In general, the hybridization between soft and rigid elements can be seen first at a system level, such as endo/exo-skeletal robots using soft pneumatic muscles [18], [19] or rigid robots articulated by soft deformable joints [20], [21]. These systems generally combine parts that are either soft or rigid, using the advantageous force-displacement relationship of the soft elements with the kinematics of the rigid elements acting as skeletons. Such stiffening soft structures can also allow to harvest more mechanical energy in soft actuators, by limiting the elastic deformation of the soft elements [22], increase their controllability [23] or allow actuation and structure integration in a compact footprint (see fig. 1).

Other HSR are built on the idea of changing their behavior depending on the situation. These systems can for example exhibit a soft behavior in a first configuration, in order to explore or interact with fragile environments, and then at another moment exhibit rigid behavior, allowing to develop high forces or to move accurately. This challenge has been addressed for example in endoscopic surgery [24], where high dexterity and low interaction forces are required during exploration or free motion phases, and high forces and precision are needed during the actual surgical tasks. Another drastic change in behavior can be seen with deployable soft mechanisms that can transition from a compact, folded state to an unfolded state [25], [26], with variable geometry systems that can actively change their morphology [27], [28], or with phase transitioning elements that can "switch" between a soft and a rigid state [29].

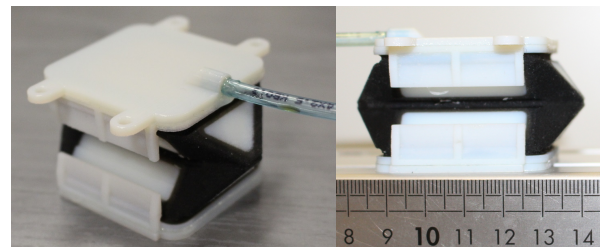


Fig. 1. An example of a hybrid origami-inspired soft/rigid pneumatic actuator able to create high-force/short-stroke motion [30]. A rigid polymer (in white) structures the deployment kinematics while a flexible elastomer (in black) forms compliant hinges and tightens the internal pneumatic room.

The main advantage of the HSR lies in their adaptability with their environment and with the task. The combinations of soft and hard, passive or active, at a materials and structural level, allow a huge number of possibilities for kinematics, interactions, modularity, etc... Because of the ever-growing diversity of medical tasks, the adaptability of HSR could play a major role in the field, but this may be overshadowed by several drawbacks that come with these systems.

Indeed aggregating elements of varied nature obviously

combines the flaws of all the combined parts. Although some of these flaws can be compensated by the combination of other elements, a system can do so much until its weakest part fails. Another issue comes from the heterogeneous nature of HSR: their manufacturing generally requires multiple steps and the formed interfaces may introduce weaknesses such as stress concentrations, peeling, chemical incompatibilities... As the consequence of a failure may be dire in the medical field, those issues have to be investigated and tackled by the community in order for those systems to be widely adopted for medical applications.

CONCLUSION

In this paper we explored briefly an emerging field of robotics that has started to sprout in the recent years: the Hybrid Soft/rigid Robots (HSR) [15], [16]. Even though medical application are still limited yet, we think that these system may become major players in this field as they may offer answers to some of the main challenges any designer has to tackle.

Although not listing exhaustively all existing HSR, this paper invites the reader to imagine how blurring the boundaries between soft and rigid mechanisms may allow the development of new emerging solutions and create new systems that can be capable, efficient and safe. We believe however that these concepts may allow the creation of a new generation of medical instruments in the near future, answering the growing need of dedicated tools for increasingly complex tasks.

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