Jamming pneumatic actuator for wearable robotics

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***Abstract*— This work describes a jamming actuator integrated into a wearable system able to improve the comfort and fitting of limb orthoses and prostheses, thanks to a stiffness and shape adaptation mechanism. The system is constituted of a wearable control unit; a soft actuator made of two jamming chambers with stiffening and elongation abilities, and an interposed inflatable chamber. This solution may guarantee proper biomechanical coupling during dynamic tasks and prevent dermatological problems and discomforts due to high pressures acting on tissues for long periods.**

Introduction

The interest in stiffness-variable systems arises from the need for devices showing both high compliance and high load-bearing capabilities. Traditional wearable robots, such as exoskeletons and prostheses, are usually made of rigid materials, not capable of stiffness or shape changes. In this field, jamming solutions appear as highly promising technologies: they are based on the application of vacuum inside envelopes of a flexible material, containing granular, fiber, or layer structures [1]. In its resting state, a jamming actuator is highly compliant; on the other hand, when vacuum pressure is applied inside the envelopes, the frictional interactions of the internal structures significantly increase the stiffness of the whole system. This technology has been successfully applied to haptics, and surgical devices, as well as for assistance and rehabilitation purpose [1]. However, these solutions generally lack a controlled shape change capability, which is of fundamental importance in wearable systems to ensure proper fitting and user comfort.

Indeed, limb orthoses and prostheses accomplish the function they are designed for by interfacing their inner surface typically made of rigid materials with the limb tissues that are much softer. In addition, these devices compress the limbs to guarantee a stable biomechanical coupling. However, the proper coupling can be affected by the shape and volume changes of the limb over time, thus resulting in altered stress distributions. This problem compromises the health of the tissue and often leads to skin irritations or even ulcers, which are the major cause of discomfort and device abandonment, especially in lower limb prostheses.

In this context, the combination of two jamming structures with inflatable chambers can allow for both a stiffness and shape adaptation mechanism, as we illustrated in [2]. Starting from this previous actuator, in this contribution the authors have changed the design and materials of the jamming structure to add elongation abilities to the stiffening properties. This allow for an easier and more durable assembly of the final system. The device can be portable/ wearable thanks to a control unit which can selectively regulate the pressure in the actuator chambers. Thus, this solution can be integrated into a prosthesis or orthosis to improve the fitting and comfort of the physical human-machine interface of the device.

Materials and methods

Design overview

The actuation concept consists of three chambers: two of them contain sandpaper sheets for the jamming actuation, while the other one is empty to allow inflation. The device is assembled by overlapping the two jamming chambers along their main dimension and by interposing the inflatable chamber transversally with respect to the jamming chambers, and at mid-length. The soft actuator can be mounted at a prosthetic or orthotic interface with the top jamming chamber in contact with the user's tissues. Starting from a planar state (step 0 in Figure 1), the configuration can be changed as follows: the bottom jamming chamber is stiffened by vacuum application, thus enabling a rigid base (step 1). The inflatable chamber is pressurized, forcing the top jamming chamber to follow the imposed displacement and to adapt to the limb shape (step 2). Finally, the top jamming chamber is stiffened (step 3), thus freezing the new shape and allowing for a rigid and well-fitted interface in contact with tissues. This guarantees a prosthesis/ orthosis stability which the inflatable chamber alone cannot achieve due to air compressibility.

If a pressure change at the limb interface is detected by a sensor, the top jamming chamber can be softened by releasing the vacuum. Then, the inlet pressure of the inflatable chamber can be regulated to achieve a proper interfacial pressure value and the new configuration can be locked by applying the vacuum to the top jamming chamber. At the same time, when the user is in a resting position (*e.g.* sitting), the system can be switched off, thus allowing pressure relief on the tissues thanks to a soft interface. In addition, according to the system requirements, the top jamming chamber can be made also with granular structures and/ or more inflatable chambers can be interposed in the middle.

* This work was supported by INAIL, the Italian National Institute for Insurance against Work-related Injuries (non-commercial entity), within the PR19-PAI-P2-MOTU++ project. The INAIL- affiliated author participated in the scientific review and approval of the study scope and objectives, as well as the final manuscript review.

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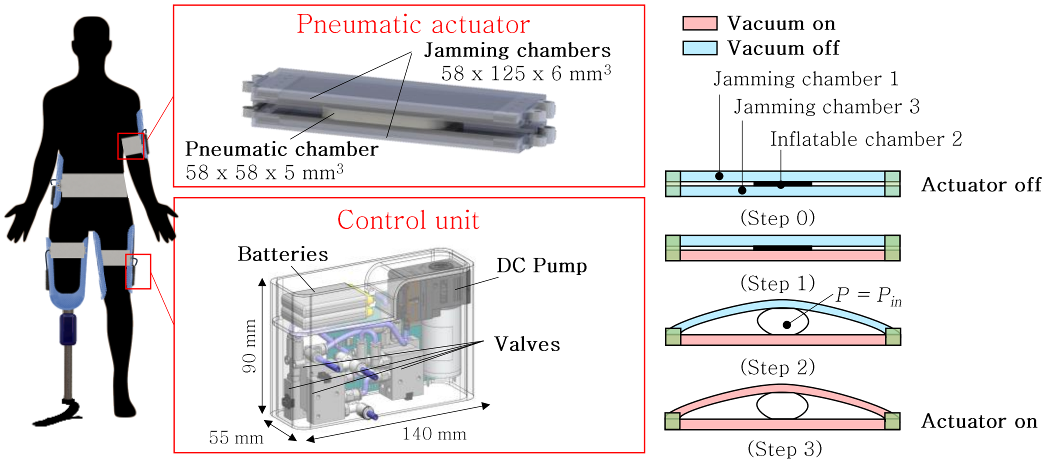

Figure 1. Stiffness- and shape-changing device for physical interfaces in wearable robotics. The proposed solution is constituted of a multiple-chamber actuator and a portable control unit. They enable to effectively modulate the shape and the stiffness of a prosthetic or orthotic interface by regulating the pressure of two jamming chambers and an interposed inflatable one.

In our previous work, the flexible chambers were made from sheets of thermo-sealed plastic and the two jamming chambers were locked together at the lateral sites by elastic bands that allowed them to move relative to each other. In this new design, the inflatable chamber is a balloon manufactured of silicone gel, while the jamming chambers consist of 10 overlapped sheets of sandpaper material, interlocked to two rigid lateral parts, which can be used also to mount the system in the wearable device (Figure 2). The layers and the rigid parts are sealed within a silicone chamber made by the molding technique and one rigid part integrates the pneumatic fitting for the tube. Thanks to this design, the jamming chamber is deformable also in tension direction, thus allowing for the stretch required to the top jamming chamber at step 2, without the need to move relative to each other at the lateral sites. In addition, the final actuator can be stretched up to 50% of its initial length to be adapted at the limb shape and it results more comfortable since softer with respect to the previous solution.

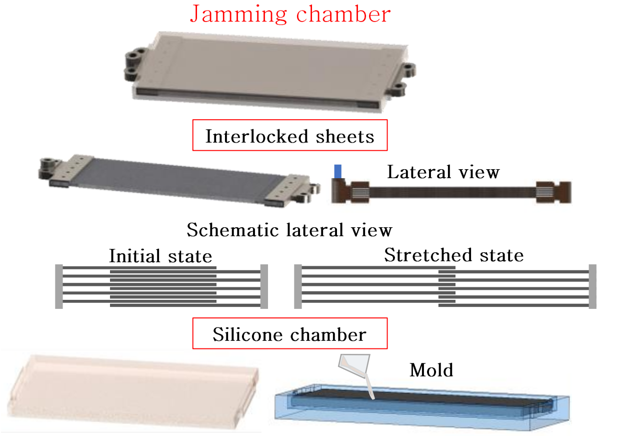

Figure 2. The layer jamming chamber is constituted of 10 interlocked sheets within a silicone chamber made by molding.

The system is activated through a control unit, which can be turned on by a mechanical switch. The micro-controller enables a DC pump to apply vacuum and pressurize the jamming and inflatable chambers by alternating the opening and closing of four solenoid valves (Figure 1). The valve connections are assembled and activated during the different steps reported in Figure 1 in such a way that the pump can be used as a compressor and a vacuum source.

Results

The final actuator and some possible application fields are shown in Figure 3.

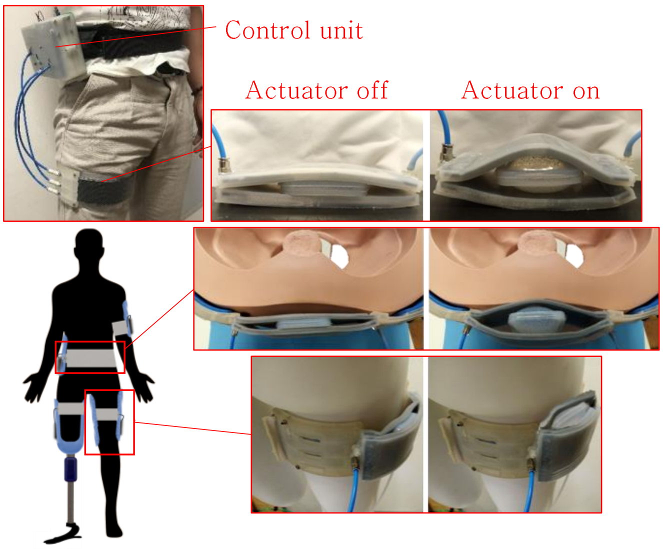

Figure 3. Possible applications of the novel wearable system.

Conclusion

The proposed variable stiffness, elongation and shape actuator has the potential to improve comfort in wearable devices. Additionally, the wearable control unit allows for an improved fitting of the physical interface. Indeed, by integrating a sensor able to measure the pressures applied to the tissues, the system can allow for the implementation of automatic control based on a specific pressure threshold, thus enabling a self-adaptation of the prosthetic / orthotic interface.

References

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