

PowerGrasp: Development Aspects for Arm Support Systems



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Abstract Exoskeletons can support workers on physically demanding tasks, but in industry they lack of acceptance. This contribution gives an insight into design aspects for upper body exoskeletons, especially how active exoskeletons for industrial applications differ from military and medical use-cases. To overcome typical rigid exoskeleton problems, we suggest the use of modular soft-exosuit support systems and therefore checked different types of soft actuation principles for their eligibility for the use on upper body joints. Most promising approach is using two-layered actuators sting of robust fabric with embedded rubber tubes as pressure chambers. By inflating the tubes, it is possible to vary the stiffness of the chambers, which can be effectively used to generate assisting forces and moments at human joints (shoulder, elbow, wrist, finger).

1 Introduction

Physically demanding manual tasks in manufacturing, logistics, handcraft and service are major contributors to early damage of the musculoskeletal system (approx. 19% of all work disabilities) and especially the spine (approx. 47% of musculoskeletal disabilities) [1] and are responsible for a loss of the gross domestic product of approximately 1% [2]. For military and rehabilitation use-cases, exoskeletons already showed that wearable systems support the muscle activity of the wearer. Nevertheless, the criteria differ largely from industrial applications (requirements for plug&play behaviour and longtime wear) and first rigid exoskeletons in assembly lines often suffer on the wearers acceptance [3]. As a result, the exoskeleton-market nowadays is mainly restricted to passive exoskeletons [4], which are practical, individually adaptive, not power restricted and much cheaper than their active counterparts. But, active exoskeletons suit the flexibility required by industrial environments more, which opens a wider industrial acceptance if the focus of the classical design-principles of exoskeletons will shift to more medically dominated topics like effects of long-term wear and ergonomics.

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2 Development Aspects

From [5, 6] and discussions with medical officers, works council, end users and management from our project partner from the automotive industry, we found the main barriers for integrating exoskeletons in industrial environments in an often not considered variety of restrictions. Those are mainly driven by economical aspects, medical concerns as well as issues concerning the level of comforts. Table 1 gives a comprehensive overview of the factors identified together with a qualitative evaluation on existing basic exoskeleton types. Rigid active exoskeleton, which are well

Table 1 Limiting factors for exoskeletons in industrial environments recorded from medical doctors, essence and [5, 6]

	Rigid-exoskeleton	Soft-exosuit
<i>Economical factors</i>		
Acquisition and maintenance costs	High	Low
Lack of generalization from specialized Use-Case	Specific to passive exos	
Adjustment to personal preferences & body type	Difficult	Easy
<i>Medical factors</i>		
Joint Misalignment between Exo and Wearer	Often	Rare
Degradation of muscle activity (due to exo)	Solvable with smart control on active exos	
Unpredictable effects of empowerment of non-ergonomic movements	Solvable with smart control on active exos	
Effects of restrictions of DoF due to compensation of movements/postures	Difficult to predict	Easier to predict
Effects of unnatural additional loading to joints and sinews	Easier to predict	Difficult to predict
<i>Comfort factors</i>		
Psychological impacts of interacting with robotic systems (safety concerns)	Higher	Lower
Joint misalignment between exoskeleton and wearer	Often	Rare
Restriction of movement	More frequent	Less frequent
Bulky exoskeleton dimension impractical in narrow industrial environments	Yes	No
Hygiene (shared use)	Higher (rare direct skin contact)	Lower (textiles)

suites for rehabilitation and military applications, would be mostly in contrast with these factors, while soft-robotic seems a suitable approach, especially when dealing with long-term medical considerations, while on the other hand still being robust, safe and also less costly.

In [7] we already proposed a rough concept for the PowerGrasp soft-exosuit system, which is primarily intended for the active support of overhead car assembly and whose key development factors are based on Table 1. Due to its modular, highly flexible setup and by supporting up to four different joints on one limb (shoulder, elbow, wrist and fingers), it can be easily adapted to changing requirements within various applications. Additional insights into the design process of the PowerGrasp soft-exosuit system from a more design and therapist perspective can be found in [6].

To figure out what type(s) of actuation units might serve the requirements of our soft-actuated system best we realised and tested different approaches. This includes 3D-printed Thermoplastic Polyurethane(TPU) based actuators, silicone-casted actuators, fabric encapsulated rubber tube actuators as well as tendon driven actuators, shown in Fig. 1.

The tendon-based is well known concerning design in robots and exoskeletons. The Application in exosuits can become troublesome though, since all of the tendon-forces will have to be redirected locally at the joints—most likely this will result in unacceptably high loads to the wearers’ bone-joint structure, especially when higher assisting loads are required. In the context of modularization, this problem gets intensified, because of the intersection problem between the separate modules. To lower the effects of friction and to allow reasonable control the integration of rigid redirecting units would be advisable—the opposite of being soft.

For inflatable actuators the production methods of monolith casting and 3D-printing show high potential for unrestricted soft actuator design as well as supporting direct inclusion of sensors and electronics. But in real-world scenarios, achievable assisting loads are limited due to the material characteristics. The permeability of the TPU-based actuator was growing with time and in case of damage, these actuators are hard to repair. As profound knowledge on long-term characteristics for these types

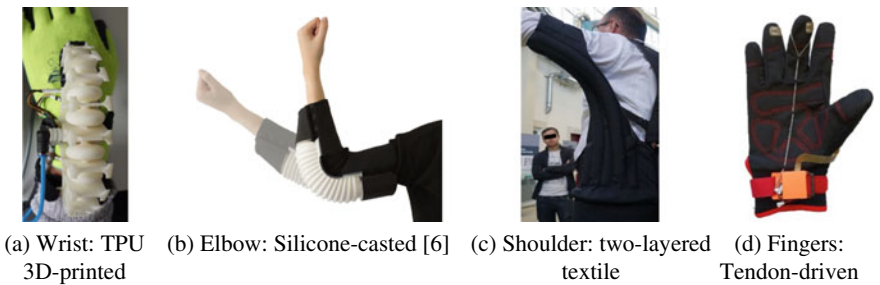


Fig. 1 Samples of tested manufacturing methods for actuator-design on different joints

of actuators is not available, we consider this fact as critical to a potential application in an industrial environment.

Alternative ways to create inflatable actuators is by using two-layer material setups. One approach uses an-isotropic structural behaviour of the outer layer (e.g. “bionic muscles”). Another uses predefined textile-patterns on the outer layer to achieve the (use-case specific) intended force vector and is mainly driven by varying the stiffness of the structure through pressure variation. Even though the design flexibility of this approach is lower compared to the generative approaches, one can still generate a large variety of actuation schemes. A major advantage, especially in the stiffness variation approach, is the high robustness of the setup due to the functional separation of inner and outer layer. The pattern of the outer layer indicates the resulting force vector as well as defines the overall flexibility and robustness against potential physical damage. The inner layer can be specifically designed to encapsulating high pressure. The functional separation also allows for easy maintenance and repair. Additionally, the actuators are flexible as textiles when depressurized - thus allowing a maximum of comfort. Because of the many advantages the actuation modules of the PowerGrasp system were finally designed according to the approach based on stiffness-control of a two-layered textile actuator—utilizing nylon polyamide fabric as outer layer and butyl tubes as inner layer—a sample can be seen in Fig. 1c. The use of Stratos-Cordura® 3-layer laminate (highly stressable) as outer layer allows the application of high pressuring states by far surpassing the other actuation methods (pressure of up to 3 bar repeatably applicable).

3 Conclusion and Discussion

To not only show technical feasibility but also to achieve high acceptance-rates for applications in industrial environment we made a revision of requirements for the design of exoskeletons and extended the scope from technical and economical aspects (classically references) by also considering medical concerns, medical long-term concerns and comfort (Table 1). We believe that considering these aspects in the design of future exoskeletons will play an essential role in the integration process of exoskeletons into the industrial environment. Next, we want to focus on identifying the control characteristics of the actuation units and include smart control schemes on the soft-exosuit to bring the benefits of the system to a maximum.

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