WEARABLE UPPER-LIMB EXOSKELETONS
PASIVNI NOSLJIVI EKSOSKELETI ZA ZGORNJE UDE

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Abstract

Exoskeletons are wearable robots aimed at working in close connection to bodily structures for rehabilitation, augmentation or assistance of human motor functions. One of the main challenges of wearable robotics is the effective achievement of human-robot symbiosis. Exoskeletons can be classified either by the type of actuation used (active, passive, and semi-active devices) or the supported body parts (lower- and upper-limb exoskeletons). Use-case scenarios for the application of wearable upper-limb exoskeletons are many, including clinical rehabilitation (rehabilitation scenario) and assistance in activities of daily living and in working environments (occupational scenario).

Key words:

exoskeletons; wearable robotics; classifications; usage scenarios; overview

Povzetek

Eksoskeleti so nosljivi roboti, namenjeni za delovanje v tesni povezavi s telesnimi strukturami za potrebe rehabilitacije, obogatitve ali pomoči človekovim gibalnim funkcijam. Eden od glavnih izzivov nosljive robotike je doseči učinkovito simbiozo človeka in robota. Eksoskelete lahko razvrstimo glede na vrsto pogona (aktivne, pasivne in polaktivne naprave) in del telesa, ki ga podpirajo (eksoskeleti za spodnje in zgornje ude). Obstajajo številne možnosti uporabe nosljivih eksoskeletov za zgornje ude, vključno s klinično rehabilitacijo (rehabilitacijski scenarij) ter pomočjo pri dnevnih aktivnostih in v delovnem okolju (zaposlitveni scenarij).

Ključne besede:

eksoskeleti; nosljiva robotika; razvrstitve; možnosti uporabe; pregled

INTRODUCTION

Exoskeletons are wearable robots aimed at working in close connection to bodily structures for rehabilitation, augmentation or assistance of human motor functions. To target these goals, an exoskeleton must be enabled with features to mimic the natural behavior of the human body and operate in perfect synergy with it. This close interaction is shared between physical and cognitive levels (1): the former consists of the physical coupling between the human and the robot, involving a flux of mechanical power between them; the latter concerns the exchange of information related to movement intentions. One of the main challenges related to wearable robotics is the effective achievement of the so-called *human-robot symbiosis*.

Exoskeletons can be classified either by the type of actuation used or the supported body parts.

As far as actuation is concerned, they can be classified in active, passive, and semi-active devices. On the one hand, active exoskeletons comprise powered actuators injecting mechanical power to the human limbs, and sensors to monitor human joint movements. These actuators can be electric motors, as well as hydraulic and pneumatic actuators or a combination of them (2). On the other hand, strictly passive exoskeletons are devices based on elastic or viscoelastic materials, like springs or dampers, that store the mechanical energy generated by specific movements to release it to support or assist a desired posture or movement (3). Both actuation paradigms carry advantages and disadvantages. Due to the absence of motors, passive devices are typically much lighter than their active counterparts; additionally, they have reduced encumbrance, high portability, and do not require any type of power supply to be used. Active devices, using motors, need electronics and power supply (either batteries or mains power supply) to operate, being consequently heavier, bulkier,

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and less portable. On the other hand, active exoskeletons can deliver higher and can generate more versatile assistive profiles. However, control algorithms and strategies are needed to decode user's movement intention to timely and effectively provide the assistance (4). Finally, *semi-active* exoskeletons represent a trade-off between the large adaptability of active devices and the greater usability of the passive ones: they use low-power servomotors to adapt the behavior of the device based on the user's needs, for example, by adapting the level of assistance or engaging/disengaging the actuation mechanisms (5).

As far as the classification according to the body segment a wearable robot is designed to support, they can be typically classified in lower- and upper-limb exoskeletons. *Lower-limb* exoskeletons target a population of users with gait impairments of different severity, such as amputees, people with muscles weakness, people who suffered a stroke, spinal cord injured patients, elderly with reduced mobility. The target population of *upper-limb* exoskeletons, instead, includes patients needing physical rehabilitation after suffering from a stroke or people who needs daily-life assistance after losing movements capabilities caused by a spinal cord injury. Over the last years, upper-limb exoskeletons have also been targeted towards occupational applications, such as in car assembly plants and manufacturing shopfloors, aiming at reducing the incidence of work-related musculoskeletal disorders (WMSDs).

Use-case scenarios for wearable upper-limb exoskeletons

Use-case scenarios for the application of wearable upper-limb exoskeletons are many, including both clinical rehabilitation and assistance in activities of daily living and in working environments.

Rehabilitation scenario

Robotic rehabilitation through upper-limb exoskeletons typically aims at restoring or improving the sensorimotor capabilities of people with different levels of neurological or physical impairments affecting the upper extremities. This sensorimotor training has the objective of reinforcing muscles and increasing the range of movement. Thanks to their high movement repeatability, exoskeletons can assist patients in performing intensive, repetitive and goal-oriented movements, also intensifying the frequency of the training. In exoskeleton-mediated physical rehabilitation, two main rehabilitation paradigms can be exploited, based on the severity of the impairment: *robot-in-charge* and *patient-in-charge* (6). In the case of patients with severe upper limb impairments (e.g., severe muscles weakness due to a stroke) the robot-in-charge paradigm is applied: the exoskeleton is controlled in a way that it forces the patient's limb to move along pre-determined path, allowing for a full passive mobilization of the limb to achieve basic motor tasks. Conversely, in the case of patients who retain a certain degree of residual movement capabilities, the patient-in-charge paradigm is adopted: the exoskeleton partially assists the patient in performing basic movements only when he/she cannot accomplish it only by him/herself, by exploiting the so-called *assistance-as-needed* strategy.

In addition to the high precision and repeatability of exoskeleton-mediated rehabilitation, such devices also offer the possibility to precisely measure movement parameters (e.g., angles, speed, torques) which can be used to monitor patients recovery along the training sessions. In this way, therapists can modulate the rehabilitation program according to objective metrics related to the actual effectiveness of a rehabilitation treatment rather than relying only on clinical scales.

Examples of upper-limb exoskeletons for rehabilitation purposes can be found in (7).

Occupational scenario

Work-related musculoskeletal disorders (WMSDs) relate to injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and spinal discs, that the work environment and performance of work have significantly contributed to induce, worse, or persist longer (8). WMSDs are a common and serious problem in industrialized societies, since they are associated to high costs to the employers, either related to direct compensation costs or indirect costs (e.g. lost wages, lost production, cost of recruiting and training replacement workers, healthcare costs for rehabilitating the affected workers). Therefore, employers are constantly looking for solutions to reduce exposure of their workers to physical risk factors that can cause WMSDs (5). Recently, to pursue occupational health and safety of their workers, companies have shown increasing interest in exoskeletons as a valuable alternative and/or complementary tool to more expensive solutions like collaborative robots. Occupational exoskeletons can be defined as personal assistive devices that can reduce the physical burden on workers while performing demanding activities, by operating synergistically with its user (9).

Currently, occupational exoskeletons for the upper limbs represent the largest fraction of wearable robots tested and employed in industrial settings, such as in car assembly facilities or in manufacturing shopfloors. Usually, they are designed to support the upper arms during prolonged overhead (e.g., in car underbody assembly) or dynamic repetitive gestures (e.g., manual material handling of goods), thus reducing the muscular strain on the human joints, such as the shoulder, with the final goal of limiting the risk for developing WMSDs.

Upper limb occupational exoskeletons are typically passive devices, since lightweight structures and high portability are features of paramount importance for their practical adoption by workers. They rely on spring mechanisms to set pre-defined and adjustable level of assistance by regulating the pre-tensioning of the spring.

Examples of upper-limb exoskeletons for occupational purposes can be found in (10).

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