# Overview and challenges for controlling back-support exoskeletons

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*Abstract*— **Exoskeletons were recently proposed to reduce the risk of musculoskeletal disorders for workers. To promote adoption of active exoskeletons in the workplace, control interfaces and strategies have to be designed that overcome practical problems. Open challenges regard sensors invasiveness and complexity, accurate user's motion detection, and adaptability in adjusting the assistance to address different tasks and users. Focusing on back-support exoskeletons, different control interfaces and strategies are discussed that aim at automatically driving and modulating the assistance, according to the activity the user is performing.**

## I. INTRODUCTION

In order to reduce workers' probability of developing musculoskeletal disorders (MSDs) [1], wearable technologies like exoskeletons have recently attracted considerable interest among the academic community and in industries [2]. As the lumbar spine is one of the body area most affected [3], back-support exoskeletons to assist lifting task are being developed. The aim is to reduce back overloading, by reducing the activity of spinal muscles [4].

In contrast to passive exoskeletons, active ones can modulate the assistance during the operation and thereby adapt to different tasks and users. The key to adaptability is a suitable control strategy that is able to precisely detect user's movement intention and provide assistance with appropriate timing and amount. Different sensors to acquire convenient input signals and the complex processing and integration of these signals are required. Moreover, minimal sensors invasiveness is necessary for exoskeleton use in real work environments.

## II. METHODS

In order to assist the user only when necessary and to not impose undesirable movement constraints, control decisions should be considered at the different control levels, as proposed in [5]. The high level has to classify the task the user is performing, by the processing and the integrating of a set of proper input signals. The control strategy (i.e. the mid level) modulates the assistance accordingly to the current task and generates reference values of the desired exoskeleton state outputs, such as torque or speed. The low level tracks these values, regulating motors outputs. In this approach, the low and the mid levels are independent of the task detection control level. Consequently, the control strategy most convenient for each specific task can be employed.

Several strategies to modulate exoskeletons assistance have been proposed in the literature. They use different sensors arrangements that acquire different input signals to detect user's intended movement. The assistance is manually triggered by the user with extra joysticks or buttons when a system is not able to automatically detect user's intention (e.g., back-support Muscle Suit [6]). Electromyography (EMG)-based strategies control exoskeletons according to the wearer's muscle activity. Surface EMG of related muscles is usually used, as for the HAL Lumbar Support [7] that is controlled by the EMG of erector spinae muscles. However, the assistance can be controlled even by the EMG of a muscle acting on a different joint, if it is activated in coordination with the target muscle during the task [8]. Control driven by mechanically intrinsic signals relies on measures that are intrinsic to the device itself. User's motion is registered thanks to Inertial Measurement Units (IMUs) and encoders and is used to modulate the exoskeleton assistance by compensating user's upper body weight against gravity (e.g., CRAY X [9]). To control a knee exoskeleton [10], IMUs and encoders were used in combination with foot sensors that measure Ground Reaction Forces (GRFs).

As regards back-support exoskeleton, two recent studies have examined the problem of detecting user's lift needs for assistance and then driving the assistance accordingly.

For Robo-Mate exoskeleton [11], two different control strategies are proposed that consider the factors related to lumbar compression: the torso inclination and the weight of the lifted object. The first strategy provides the assistance proportionally to the torso inclination, measured by an IMU mounted on the exoskeleton. The second strategy provides the assistance proportionally to the EMG of the forearm muscles, as during grasping and holding forearm muscles activity increases with object weight.

In [12] an algorithm is proposed that detects lift movement using encoders and an IMU embedded in the Active Pelvis Orthosis (APO). Encoders measure the left and the right hip joint angles used to detect the transition between the different phases of the lifting task. If a lift is detected, the estimation of the thigh angle (provided thanks to the additional IMU) is used to confirm the current lift phase. Knowing the current user's movement, the assistive torque is computed using only hip angle measures from the encoders.

In both studies, back muscles EMG activity was analysed to evaluate the effectiveness of the exoskeleton in reducing muscular activation during lifting. Both studies showed a significant reduction (around 30%) of muscle activity.

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## III. DISCUSSION

To promote exoskeletons use in industries, the invasiveness of the sensors and the ease of use of the device have to be achieved while ensuring adaptability in order to address different users, tasks and assistance requirements.

As regards sensors, the aim is to minimise instrumentation complexity while maximising the information we can extract from them to recognise movements and tasks. Manual trigger main limitation is that users are required to use their hands to control the system. This increases cognitive burden, makes the task intermittent, and additionally introduces physical complications since users hands are usually busy to lift objects. Considering industrial workplace, EMG signal variability (with time, fatigue, sweat, skin artefacts) and the invasiveness of the electrodes limit EMG-based strategies use in this context. By contrast, mechanically intrinsic controllers employ IMUs and encoders that are easy to integrate into an exoskeleton. Invasiveness problem would emerge with GRF sensors, that can estimate the presence of an external weight, but cannot be integrated into the structure and, furthermore, may limit wearers movement. Nevertheless, mechanically intrinsic control main limitation is that they usually required an accurate model of the body.

As concerns controller design, the Robo-Mate exoskeleton [11] implements only the mid and the low levels. The assistance is thus given when a particular movement, and not a complete task, is recognised. This approach permits, therefore, to assist tasks not standardised (e.g. asymmetric lifting) that require some type of help as the user is bending his torso or holding an object. Indeed, the gravity compensation assistance is given to the user both in the lowering and in the lifting phase. Moreover, additional assistance is given proportionally to the weight of the lifted object, estimated by forearm muscles activity. However, unwanted forces or movement constraints are possible, as the system is not able to detect and switch off when different activities are being performed (e.g., walking, taking stairs, sitting for which this type of assistance is not meaningful).

By contrast, the approach introduced for the APO device [12] implements a lift detection algorithm as a high level controller to trigger the assistance automatically. The advantage of this approach is that it is possible to assist the user specifically for the target task, avoiding constraints or undesirable assistive forces corresponding to different activities. Embedded and minimally invasive sensors ensure an easy implementation in real practical applications, but they do not provide information about external objects weight. Nevertheless, controller effectiveness relies on the capability of discerning accurately the lifting task. Accuracy was proved to be higher than 97%, also for different lifting techniques and speeds. However, several assumptions have been made to strictly define the lifting task: grasping must happen before lifting and has a predetermined time threshold, the hip angle has to reach the peak in the grasping phase, the lifting is symmetric. Therefore, only standardised tasks can be assisted effectively. Moreover, the high level is designed to detect the tasks at the beginning of the lift movement, thereby the user is not assisted during the lowering phase to support his own or a potential external weight. In this contest, a future challenge could be to design an algorithm able to classify many different tasks that require assistance and then implement the different control strategies accordingly.

To make control strategies effective, the major causes of workers' MSDs have to be investigated. As concerns lifting task assistance, in [11] two key factors have been found that mostly affect lumbar compression: torso inclination and the mass of the object being handled.

## IV. CONCLUSION

Recent progress in research has been contributing to promoting adoption of back-support exoskeletons in real working scenarios. The challenges that active devices have to address were discussed, regarding integration of the acquisition systems in the structure, strategies to modulate the assistance during the operation and control system design. In our opinion, the underlined advantages of a task detection level should be further exploited, together with more advanced strategy for targeted assistance. Future works will focus on the classification of different tasks and the delineation of specific control strategies for each of them, as authors believe that could promote exoskeletons employment significantly.

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