Final Defense

PhD in Bioengineering — POLITECNICO MILANO 1863

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PhD student:	**LAZZARONI MARIA – XXXII Cycle**

Thesis title:	**Control strategies for a back-support exoskeleton to assist workers in manual material handling**

Advisor:	**Prof.sa ELENA DE MOMI**
Co-Advisor:	**Prof. JESUS ORTIZ**

PhD student:	**LORENZINI MARTA – XXXII Cycle**

Thesis title:	***A framework for the evaluation and improvement of human ergonomics in human-robot collaboration***

Advisor:	**Prof.sa ELENA DE MOMI**
Co-Advisor:	**Prof. ARASH AJOUDANI**

PhD student:	**LAZZARONI MARIA – XXXII Cycle**

Thesis title:	**Control strategies for a back-support exoskeleton to assist workers in manual material handling**

Advisor:	**Prof.sa ELENA DE MOMI**
Co-Advisor:	**Prof. JESUS ORTIZ**

Abstract:

Back-support occupational exoskeletons are being developed and introduced in the workplace in order to reduce back-related musculoskeletal disorders associated with the execution of manual material handling activities. Existing evidence tends to confirm the benefits of back-support exoskeletons for preventing low back pain associated with the execution of manual material handling tasks that involve trunk flexion/extension or static bending postures. Compared to passive devices, active exoskeletons are considered more versatile, because of the possibility to modulate the assistance during the operation. Effective modulation of the assistance is made by means of appropriate control strategies.

Considering the industrial application, the assistance provided by an exoskeleton should adapt according to the different tasks performed by workers. In particular, each specific task implies different movements and thus different assistance requirements. An active back-support exoskeleton has the possibility to implement multiple control strategies in the same device and to interchangeably use them to assist the current task the user is performing.

The present work contributes to enhancing the versatility of active back-support exoskeletons by proposing solutions for assisting different manual material handling tasks executed in the workplace. The aim is to improve assistance effectiveness and users' acceptance for exploiting the support of an active back-support exoskeleton in a wider range of applications. Considering the industrial workplace, the main factors to be considered when selecting a control strategy are its practical functionality and usability (regarding user's residual mobility, physical comfort, whole device encumbrance, and ease of use) and its effectiveness in reducing musculoskeletal disorders risk factors.
In this context, the core contributions of this doctoral research addressed two manual material handling tasks, namely lifting and lowering tasks and pulling task.
Starting from the results obtained with the biomechanical analysis, a control strategy for assisting lifting and lowering tasks was implemented based on the user's trunk angular acceleration. The control strategy presented, by taking into account the dynamics of the user's movement, is able to adapt the assistance to the different phases of the tasks. In particular, this control strategy improves the pattern of the assistive torque by reducing the hindrance perceived by the user when flexing the torso in the lowering phase and increasing the support in timing with the user's need (i.e., beginning of lifting).
The strategy effectiveness was experimentally evaluated relative to the condition without the exoskeleton as well as against existing strategies for comparison. Using the exoskeleton during lifting and lowering tasks reduced the peak compression force on the L5S1 disc by up to 16%, with all the control strategies. Substantial differences between the control strategies in the reductions of compression force, lumbar moment and back muscle activation were not observed. However, the speed reduction for the dynamic control strategy appears to be lower compared to the other strategies, although no statistical significance was found. This result encourages further investigation as it seems to support our initial hypothesis that the new control strategy provides more appropriate support to the tasks, improving the timing of the assistance in relation to the typical dynamics of the movement, with positive improvement in intuitiveness and comfort in use, and limiting the exoskeleton's negative impact on productivity (i.e., the hindrance to fast movement is reduced).
In the second place, this thesis proposes the first control strategy to assist the execution of pulling task. A preliminary control strategy was designed, based on the activation of the user's forearm muscles. The assistive torque modulating with the forearm muscle is expected to adapt to the user's need of assistance and in particular to the mass of the pulled object, as the activity of forearm muscles is considered to be an indication of grip strength.
An experimental evaluation was performed to assess the effects of the pulling strategy on assisting the execution of the task. Objective measurements, in terms of users' back muscle activation reduction, show the promising benefit provided by the exoskeleton assistance. By reducing the activation of these muscles during the execution of the task, their contribution to lumbar compression is expected to decrease.

PhD student: **LORENZINI MARTA – XXXII Cycle**

Thesis title: ***A framework for the evaluation and improvement of human ergonomics in human-robot collaboration***

Advisor: **Prof.sa ELENA DE MOMI**
Co-Advisor: **Prof. ARASH AJOUDANI**

Abstract:
Work-related musculoskeletal disorders (WMSDs) are impairments of the human body structures that are provoked or worsened primarily by work and by the effects of the immediate environment in which work is conducted. WMSDs are the leading cause of disability in four of the six World Health Organization regions, with substantial economic costs and a severe impact on the quality of life. The careful monitoring of workers' exposure to the factors which may contribute to their development is of crucial importance in industrial environments, aiming to lay the foundation of risk prevention and reduction programs. Nevertheless, in the brand-new industrial scenario, featured by frequently varying work flows and unstructured work stations, the traditional view of occupational ergonomics is rather weak and barely applicable. In fact, the most widely used tools are still "pen-and-paper" observational approaches, which need to be carried out in an off-line stage. On the other hand, numerous techniques have been proposed by researchers to estimate humans'

physical load, relying on direct measurements collected on the human body through sensors devices. But complex laboratory-based approaches are hardly personalisable and impractical for industrial settings. Accordingly, the scientific objective of this thesis is to fill in this gap, by introducing a novel framework for the evaluation and improvement of human ergonomics, which implements online, personalisable, and reconfigurable strategies to account for workers' ergonomic demands.

The proposed framework entails three main components: the observation layer, the warning layer, and the action layer.

Within the observation layer, data about the humans' motion and the interaction forces they exchange with the environment are measured with fit-for-industry sensor devices, and a subject-specific model of the human body is identified. Their integration enables to define and estimate a human ergonomics monitoring system. The latter is a comprehensive set of indexes to assess humans' physical exposure, accounting online for multiple ergonomic risk factors to the development of WMSDs. Both kinematic and dynamic aspects are addressed, taking into account the whole-body human.

To validate the proposed monitoring system, an experimental analysis is conducted on twelve subjects considering three different tasks, which represents typical jobs in manufacturing industries and, additionally, are associated to different potential risk factors. As a result, the ergonomic indexes that better explain the physical load required in each analysed activity are established, confirmed by the outcome of a surface electromyography (sEMG) analysis.

Within the warning layer, the levels of the ergonomic risk associated with the estimated indexes are determined. Then, by taking advantage of intuitive and practical feedback interfaces (i.e. visual and vibrotactile), this information is conveyed to the workers to improve their risk-awareness. Both the proposed solutions prove their potential in assisting humans in their occupational activities through corrective feedback interfaces.

Within the action layer, an optimisation procedure is adopted to estimate a more ergonomic human body configuration by minimising a selected ergonomic index according to certain constraints. Subsequently, a worker can be facilitated to achieve such an optimal condition by following the guidance of a collaborative robot, thus mitigating the effect of the associated risk factor. The experimental investigations conducted to evaluate the performance of this HRC framework provide evidence of its capability to reduce the effort on human joints, due to the robot reactive behaviour. Such findings are supported by the results of a sEMG analysis. The proposed strategy shows promising capabilities to reduce humans' exposure to the factors that may determine WMSDs, ensuring workers' well being while enforcing productivity. Therewith, its key strength in the applicability to realistic industrial environments is exhibited.

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