Summary

Within Industry 4.0, the robotic innovations and applications focus on the simultaneous presence of robots and workers sharing the same workstation. The role of robots has changed during the last decades, starting from substituting workers in heavy and hard tasks to assisting them in performing works. Merging robotics and human skills, as creativity and decision-making, seems to be a promising solution for many tasks that cannot be totally automated. In this contest also wearable robotics is introduced in manufacturing and industrial fields. Occupational health and safety are principal objects of interest due to the impact of work-related accidents and diseases on the work population. Among those, low back pain and injuries are the most common.

Industrial exoskeletons are robotic, mechanical devices directly worn by the users. The principal aim of an industrial exoskeleton is the partial reduction of the muscular efforts of the operator during working gesture. The exoskeleton can be defined as a personal daily use equipment and, for this reason, the acceptability and wearability by the operators gain crucial importance in design and development.

The aim of the present PhD thesis is the analysis, design and development of a powered exoskeleton prototype for the trunk support in industrial tasks of lifting and manual handling.

After briefly introducing the biomechanics and physiology of the human spine, the kinematics and dynamics connected to the risk of injuries are analysed. Then a literature review of current trunk support exoskeletons is conducted with the attempt to highlight current open challenges. Due to the specific function of the assistive device, ergonomic guidelines and lifting strategies are explored.

Mechanical and assistance characteristics of a passive commercial trunk-support exoskeleton are analyzed. Experimental tests are conducted to evaluate the device performances and to stress the benefits and drawbacks of the system in order to point out possible improvements.

A model-based approach is selected for the investigation of human-exoskeleton interaction, with attention to the effects of the wearable device on human body biomechanical loads. 3D multibody models of the human body, exoskeleton and interface are implemented. The simulation analyses of different exoskeleton configurations and the biomechanical investigation of human joint efforts allow the final characterization of a suitable architecture and assistance law for the powered system. The new system should be able to recognize the lifting strategy adopted by the user and to differentiate the assistance based on human body kinematics. The support strategy is designed to be user and task specific.

Based on experimental and computational analyses, the powered prototype of the trunk support exoskeleton is developed. Both the mechanical and control architectures are object of the present study.

The mechanical design and the implementation of the powered system are deeply presented, starting from the identification of the maximum supplied torque. Mechanical components are selected with the attempt to provide the required assistance performance with limited encumbrance and weight of the final structure. The exoskeleton supplies assistance to the user through electric actuators and a proper designed powered joint. The study presents the CAD design of different solutions in order to ensure compactness and lightweight of the final proposal.

The control system is based on two loops: model-based control (high level) for the definition of the desired torque and torque control (low level) for the closed loop on the motor output. The hardware system and the selected electronic components are defined for the implementation of the exoskeleton two-level control architecture.

CONCEPTUAL MAP of the Thesis