論文の内容の要旨

Power Assist Robot Design
Inspired by Biological Control and Actuation Mechanisms

(生物の制御と操作メカニズムに学ぶ パワーアシストロボットの設計)

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The objective of this work is to design control strategies to increase safety, robustness, force output, response time for power assist robots, inspiring by biological control strategy and actuation mechanisms found in humans and animals.

Power assist robotics is rising in interest for three main reasons. Power assist devices increase performances such as muscle strength and endurance for workers in health-care centers and hospitals, wild land firefighters, disaster relief workers, soldiers, heavy labor factories, and in any other emergency situation. Power assist devices support elderly and disable people. Rehabilitation process and physical training carried out with the use of power assist devices have been shown to be faster, more intense, more motivational via audiovisual feedback and game mode, and easier reproducible do to quantitative outcome measurements.

Although big progress have been done in recent years, there are still three main challenging aspects where more investigation and innovative solutions are needed: safety for the user and the surrounding environment, a more comfortable interaction in a human-friendly prospective, an increase in performances such as response, power production and energy efficiency.

Most of the ongoing researches are focused on mechanical and control design with a pure engineering approach, neglecting the inspirational power of nature. Biologically inspired robotics is an process that goes beyond merely copying what nature shows at first sight. It involves three phases: observation and understanding nature, design robots not copying from nature, but embedding and resembling the desired nature functionalities, and finally implementation and development.

Understanding humans and animal functionalities and the consequent implementation on robot applications has shown to improve robot performances such as robustness, safety, and flexibility in a variety of complex dynamic tasks.

In order to improve safety, robustness, actuation power, and response time for power assist robots, in this work biological motion control and actuation mechanism of humans and animals play the inspirational roles.

Regarding the biological inspiration for motion control, humans and animals high vary impedance of their body to stabilize unstable dynamics. On the basis of this a new approach to force control for power assist devices — Force Sensor-less Power Assist Control (FSPAC) with variable impedance — is proposed. The proposed FSPAC with variable impedance is successfully implementation on an experimental door actuated by either a linear motor (low friction stem) or by a rotational motor and a balls-crew (high friction system). Comparison with traditional FSPAC is carried out. The superiority of the proposed FSPAC with variable impedance in respect to the traditional FPAC with constant impedance, in terms of safety, robustness and smooth assistance have been experimentally shown.

As for the biological inspiration for actuation mechanism design, humans and animals presents bi-articular muscles — muscles that span joints — which play a fundamental role for mechanical energy transfer, impedance modulation and stabilization of human and animal dynamics.

In the design of bi-articularly actuated robots, our focus is on the resolution of the redundancy actuation. Two new approaches — the Infinity Norm and the Non Linear Phase Different Control (NLPDC) — are proposed. A human-like actuated robot named BiWi — Bi-articularly actuated Wi-re driven robot arm — is developed and used as an experimental apparatus to compare the two proposed redundancy resolution approach with the three traditional approaches — Phase Different Control (PDC), Pseudo inverse matrix, and Linear Programming.

The superiority of the proposed infinity norm approach in terms of maximum force production in respect to the pseudo-inverse matrix approach, output force precision in respect to the Phase Different Control approach, and in lower computational need in respect to the Linear Programming approach, is shown. The proposed infinity norm approach is suitable to increase the performances of any system with 3 inputs and 2 outputs.

As for the NLPDC approach, it is shown that it is the only method capable of calculating in a precise way a the maximum output force that can be produce at the end effector of a bi-articularly actuated robot arm given the joint actuator maximum torques, with a closed form equation.