Design and Virtual Prototyping of a Variable Stiffness Joint via Shape Optimization in a CAD/CAE Environment

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Keywords: *Safe Human-Machine interaction, Variable Stiffness Actuators, Integrated CAD/CAE Simulation, Shape Optimization, Virtual and Physical Prototype*

SOMMARIO ESTESO / EXTENDED ABSTRACT

During the latest decade, collaborative robots, namely machines specifically designed for the physical interaction with humans, have been gradually making their transition from laboratories to real-world applications [1]. Naturally, whenever the envisaged task would benefit form physical human-machine interaction, safety and dependability become issues of paramount importance [2]. Nonetheless, especially when dealing with collaborative operations in the manufacturing industry, safety regulations may lead the plant designer to face opposite goals. On one hand, robots should indeed be designed so as to never cause harm to people (both during regular functioning or in case of failure). On the other hand, the wide-spread use of industrial manipulators traditionally leverages on their capabilities to carry rather high payloads, while achieving a very fast and precise positioning of the end-effector. These requirements are usually pursued by coupling powerful actuation systems with extremely rigid mechanical structures, which hardly comply with safety needs whenever the workers are supposed to enter the robot workspace. Therefore, the engineering challenge when designing collaborative robotics systems, which have to be safe and efficient at the same time, is usually tackled via the following strategies: *i)* by enhancing the robot sensory apparatus; *ii)* by adopting active control strategies; *iii)* by reducing the inertia of any moving part employing lightweight materials whenever possible. In parallel, as previously proven by several researchers [3], another way to actually implement safe machines for collaborative tasks is to increase (rather than minimize) the inherent compliance of their mechanical structure [4], simultaneously introducing the possibility to actively vary such compliance during the robot movements. This capability can be implemented, for instance, by means of Variable Stiffness Joints (VSJ), namely particular actuation systems which allow to independently control the position of an output link along with the transmission stiffness. In

GEF 2018 - Dodicesima Giornata di Studio Ettore Funaioli
20 luglio 2018, Bologna

light of this consideration, the present talk describes the design of a novel VSJ architecture, depicted in Fig. 1a. The VSJ can achieve stiffness modulation via the use of a pair of compliant mechanisms with distributed compliance, which act as nonlinear springs with proper torque-deflection characteristic. These elastic elements are composed of slender beams whose neutral axis is described by a spline curve with non-trivial shape. The beam geometry is determined by leveraging on a CAD/CAE framework that allows for the shape optimization of complex flexures. In particular, the design method makes use of the modeling and simulation capabilities of a parametric CAD seamlessly connected to a FEM tool. For validation purposes, proof-concept 3D printed prototypes of both elastic elements (Fig. 1a) and overall VSJ (Fig. 1b) are finally produced and tested (Fig. 1c). Experimental results fully confirm that the VSJ behaves as expected.

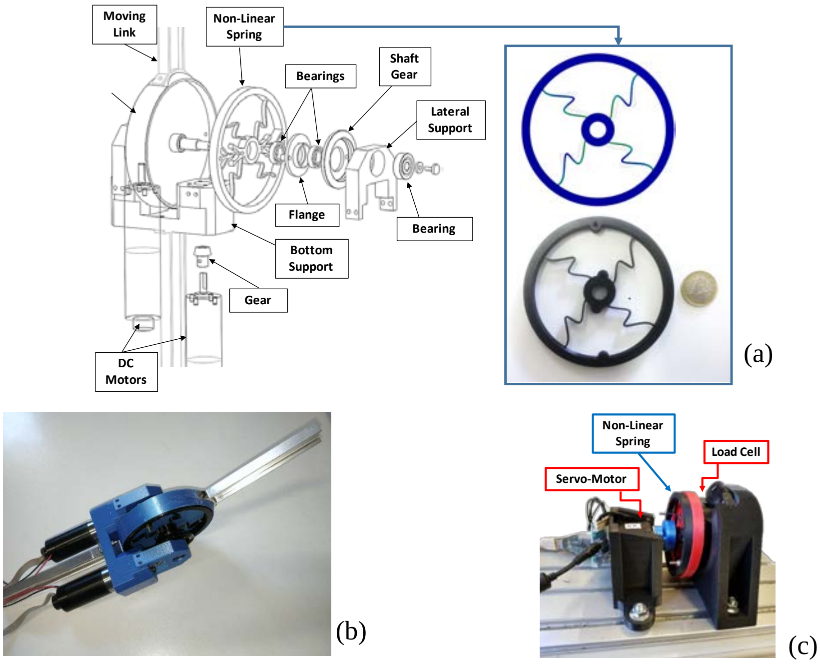

Figure 1. The novel variable stiffness joint: CAD exploded view and details of spring design (a); VSJ prototype (b); rig for spring testing (c).

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