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DOCTOR OF ENGINEERING SCIENCES

of **Thierry Hubert**

The public defense will take place on **Monday 27th April 2026 at 5pm** in room **D.2.01** (Building D, VUB Main Campus)

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COBOTS DESIGNED FOR STRENGTH, NOT STIFFNESS: STRUCTURAL OPTIMIZATION AND VIBRATION CONTROL

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Abstract of the PhD research

This dissertation investigates the structural optimization and control of collaborative robotic manipulators. It focuses on reducing mass, improving energy usage, and maintaining performance in systems designed for human interaction. Conventional industrial robots rely on stiffness for precision, resulting in heavy structures that limit adaptability and increase energy demand. This work proposes a strength-based design approach that enables lower mass and improved operational characteristics. The project aims to develop a new generation of cobots with a target payload-to-mass ratio of 1:1. This ambitious goal necessitates a departure from conventional stiffness-driven design and calls for innovative approaches to structural optimization and control. The dissertation begins by examining the limitations of existing cobots, including excessive mass, low payload efficiency, and reduced operational speed due to safety constraints imposed by standards such as ISO/TS 15066. It proposes a shift toward strength-driven design, where structural components are optimized for load-bearing capacity rather than rigidity. This approach enables significant mass reduction, which in turn improves safety, energy consumption, and dynamic performance. A multi-stage optimization framework is developed, encompassing parametric, topology, shape, and generative design methodologies. Parametric optimization is first applied to a reference platform (UR16e), demonstrating that relaxing stiffness constraints can yield a 74% improvement in payload-to-mass ratio, a 25% reduction in impact forces, and a 34% decrease in energy consumption. These findings are validated through CAD modelling, finite element analysis, and experimental testing. The study then transitions to topology optimization, which allows for free-form material redistribution within a defined design space. Using the KUKA iiwa 14 as a new reference platform, topology-optimized links are developed and integrated into a 3-degree-of-freedom manipulator. The optimized links exhibit significantly lower mass while maintaining structural integrity, with first natural frequencies around 1.5 Hz. Comparative experiments between the topology-optimized flexible link manipulator and a rigid link manipulator reveal that the flexible link manipulator consumes less energy and requires lower joint torques. To address the dynamic limitations introduced by structural flexibility, a novel adaptive vibration control system is de-signed and implemented. The controller uses strain gauge feedback and gain scheduling based on joint configuration and payload, enabling real-time suppression of oscillations. System identification is performed using multisine excitation and Best Linear Approximation for modelling. Edge-case tuning of the controller ensures robustness across the manipulator's workspace. Experimental validation based on ISO9283 standards shows that the flexible link manipulator, when equipped with vibration control, achieves repeatability within 0.138 mm with a 10 kg payload, comparable to commercial rigid robots. The controller also reduces settling time by 94% and maintains energy efficiency, with the energy saved from lightweight design outweighing the additional consumption due to active damping. Overall, this work demonstrates that flexible link manipulators, when properly optimized and controlled, can meet industrial performance standards while offering substantial benefits in terms of safety and energy efficiency. It lays the groundwork for a new generation of collaborative robots designed for strength, not stiffness.