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DOCTOR OF ENGINEERING SCIENCES

of **Amin Khorasani**

The public defense will take place on **Monday 11th May 2026 at 5pm** in room **D.2.01** (Building D, VUB Main Campus)

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DUAL MOTOR ACTUATION (DMA): POTENTIAL FOR SAFE AND ENERGY EFFICIENT HUMAN ROBOT INTERACTION

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Abstract of the PhD research

Safe and responsive interaction between humans and robots remains a primary challenge in collaborative robotics. As robotic systems advance in speed, weight, and capability, their actuators must deliver high dynamic performance while ensuring intrinsic safety during physical contact. This doctoral research, conducted within the ELYSA project, addresses this challenge by examining the role of actuation in collision safety and energy efficiency, with particular emphasis on Dual Motor Actuators (DMAs) as a redundant actuation topology for next-generation collaborative robots. The ELYSA project aimed to design a safe, lightweight, and energy-efficient robotic arm through three technological pillars: (1) lightweight and intrinsically safe arm design, (2) remote actuation for reducing moving mass, and (3) redundant actuation for improved safety, adaptability, and energy efficiency. This thesis focuses on the third pillar, examining how kinematically redundant actuators can influence energy efficiency and improve safety and performance in human-robot interaction (HRI). The DMA architecture couples two motors through a differential transmission, enabling the dynamic redistribution of kinetic energy between the two drive trains. This configuration allows real-time modulation of equivalent reflected inertia, providing inherent advantages for collision safety and impedance control. Modeling, simulation, and experimental validation demonstrate that the DMA topology can enable a substantial reduction of reflected inertia compared to single drive actuators, thereby improving backdrivability, compliance, and impact resilience. Furthermore, implementing impedance control on this redundant structure yields a stable second-order dynamic response that effectively damps external disturbances while preserving control stability and boundedness. A comprehensive analytical and simulation framework was developed to study collision dynamics in human-robot interaction, incorporating stiffness, damping, and inertial effects. Integrating the DMA into this framework revealed that shaping the actuator's internal energy distribution can passively reduce transmitted forces during contact, enabling intrinsically safer robot behavior even in uncontrolled impact scenarios. These findings outline a clear direction for developing collaborative robots that combine agility with mechanical compliance, ensuring safety without sacrificing performance. Although redundancy introduces additional complexity and potential energy losses, this research proposes a task-oriented design methodology to balance safety benefits with acceptable energy consumption and mass constraints. Rather than positioning the DMA as an inherently energy-efficient solution, the study offers practical design guidelines for selecting subcomponents that maintain safety advantages while achieving reasonable efficiency and compactness. Complementary mechanical subsystems were investigated in parallel to this PhD thesis as master projects to further enhance actuator performance and energy efficiency, including bidirectional roller clutches as passive, energy-efficient braking mechanisms and compact concentric DMA architectures utilizing axial flux motor technology for high torque density and reduced inertia. In summary, this research establishes a coherent framework connecting redundant actuation, intrinsic safety, and energy-aware design. It demonstrates that actuator architecture, through increased mechanical freedom and compliant control, plays a decisive role in mitigating collisions, shaping impedance, and achieving safe, efficient physical interaction between humans and robots.