VRIJE UNIVERSITEIT BRUSSEL

The faculty of Engineering of the Vrije Universiteit Brussel invites you to attend the public defense leading to the degree of

DOCTOR OF ENGINEERING SCIENCES

of **Constantin Florian Scholz**

The public defense will take place on **Tuesday 23rd September 2025 at 4 pm** in room **D.2.01** (Building D, VUB Main Campus)

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ENHANCING HUMAN-ROBOT COLLABORATION SAFETY THROUGH MULTIMODAL COMMUNICATION AND SENSOR INTEGRATION

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Abstract of the PhD research

Collaborative robots (cobots) are increasingly deployed in industrial environments to bridge labour shortages and enhance manufacturing flexibility. However, their adoption is constrained by robot understanding and safety challenges, limiting usability and efficiency in shared cooperative and collaborative workspaces. This thesis investigates two critical aspects of human-robot collaboration: (1) novel interaction interfaces for robot-to-human communication and (2) sensor integration for intelligent situational awareness, ensuring an optimal balance between speed and safety.

In the first part, this thesis explores how cobots can more effectively communicate their intentions to human operators, ensuring mutual understanding and trust. Current cobots lack expressive features especially around the end-effector, making their actions challenging to interpret. Two communication interfaces were developed and implemented. The first interface is a flexible skin-like interface to express the robot's internal states and monitor task progress. The second interface is Antropo, an anthropomorphic platform with eye gaze, light-based feedback, and sound cues. With these interfaces, the role of expressing internal states, task progress, social cues, and dynamic visual displays has been investigated in industrial settings. These studies were conducted in collaboration with industry partners, demonstrating that these interfaces enhance operator awareness, usability, and acceptance of cobots in real-world applications.

The second part of this thesis focuses on advancing safety in human-robot collaboration through safety sensor technologies. A PRISMA methodology was adopted to systematically analyse research papers and patents to identify key trends, integration challenges, and gaps in current safety systems. The results highlight the limitations of current proximity sensors, including low resolution, limited range, and slow response times, underscoring the need for higher frame rates and adaptive sensing. Based on these insights, SAFEBOT, an on-robot multimodal proximity perception system, was designed to enable real-time occupancy mapping, speed and separation monitoring (SSM), and path planning. Unlike traditional force-torque sensing that relies on impact sensing, SAFEBOT integrates multiple sensing modalities, generating a high-resolution dynamic occupancy map that enhances adaptive safety strategies and supports the future development of intelligent workspaces. This work has been validated in lab-based settings replicating various industrial use cases to ensure readiness for implementation in the industry.

This research advances robot-to-human communication and on-robot safety perception, enabling cobots to become more intuitive, adaptable, and capable of operating safely alongside humans without physical barriers. The findings contribute to the next generation of robotic systems, including humanoids and autonomous robots, where real-time perception and interactive behaviours are essential for safety and efficiency across various applications.