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 **Anand Varadharajan**

The public defense will take place on **Monday 20th April 2026 at 4pm** in room **D.2.01** (Building D, VUB Main Campus)

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ROLLER-GEAR TRANSMISSION SYSTEM TAILORED FOR ACTUATORS IN HUMAN-CENTERED ROBOTICS

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Abstract of the PhD research

Actuators remain one of the most critical challenges in modern robotics, with more than two-thirds of power losses occurring within high-ratio gearboxes or transmission systems. These losses contribute to increased bulkiness, limiting the payload capacity as robots end up carrying more of their own weight than the intended load. Among the common gearbox choices — planetary gears, harmonic drives, and cycloidal gearboxes — planetary gear trains (PGTs) are widely recognized for their versatility and reliability. However, traditional high-ratio PGT configurations, while enabling compact torque amplification, often suffer from extreme efficiency losses.

The efficiency of high-ratio PGTs is mainly constrained by the meshing efficiency of the engaging gears in each stage. Such gear wheels, predominantly with involute tooth profiles, operate with a meshing efficiency of around 98–99%. Yet, the overall efficiency of the gearbox drops to below 70% when gear ratios of a few hundred are exceeded. Unconventional gear profiles have the potential to solve efficiency issues in high-ratio planetary gearboxes.

Apart from easy manufacturability and insensitivity to center distance deviations, traditional involute gears dominate due to their well-established frameworks supported by commercial design software and manufacturing methods. However, their increased noise levels at high speeds, incompatibility with low-tooth-count gearing, and significant wear at the start and end of meshing due to higher sliding velocities are critical disadvantages. An alternative to involute gears that operates at a higher meshing efficiency would not only enhance the overall efficiency of high-ratio gearboxes but also challenge the conventional preference for involute gears.

Through this research, we establish that the efficiency of high-ratio planetary gear train configurations can be enhanced by optimizing the gear profile to minimize sliding velocities and promote rolling torque transfer in gear wheels. Non-involute gear profiles with minimal transverse contact ratios and increased overlap ratios operate on rolling-based torque transfer and are beneficial for increasing efficiency. Furthermore, redundant rollers employed in motion transfer along with the gears prove to be important for two reasons: (i) ensuring proper meshing conditions with respect to gearbox assembly, regardless of the gear profile, and (ii) reducing the free-spinning torque of the gearbox, as sliding losses are further reduced in the gear mesh. The result is a more efficient power transmission system for modern robotic actuators, while also improving back-drivability and reducing backlash—both critical for robotic applications.