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A high efficient, high gear ratio Planetary Gear Transmission for Human-Centred Robotics

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***Abstract*—In many robotic applications, high torque density and highly efficient actuators are crucial to manage high-torque movements without compromising mobility through added weight and size. Engineers traditionally design these actuators using electric motors combined with high-ratio speed reducers like harmonic and cycloidal drives, or lever arms, to generate the necessary torque. However, these setups often face limitations such as high cost, low efficiency, and non-backdrivability. At our lab, we are studying a novel high-gear-ratio transmission based on a Wolfrom planetary gear train, which achieves exceptional speed ratios (over 200:1) while maintaining energy efficiency superior to commercial solutions across the entire operating range.**

Our previous work has demonstrated promising outcomes and confirmed the theoretical framework. Through this poster, we aim to present and discuss the results of our latest prototype. Initial tests reveal a peak efficiency exceeding 80% for a gear ratio of 222:1, a weight of only 650g, a repeatable peak torque of 80Nm, and a backdriving torque below 1Nm.

***Index Terms*—Efficient Actuators, Robotic Actuators, High-Ratio Gearboxes, Planetary Gear Trains, Compound Planetary Gear Trains, Wolfrom Gearbox**

I. Background

Gearboxes play a crucial role in drivetrain systems, as they allow to reshape the operating range of the motor to that of the application. In traditional industrial robotics, the focus has been on achieving extreme positioning accuracy, leading to innovations in high-ratio gearboxes like Cycloid Drives and Harmonic Drives (HDs). However, in modern robotic devices such as collaborative robots (cobots), mobile robots, exoskeletons, and prostheses, the emphasis has shifted towards torque density [1]. HDs have emerged as a dominant choice in these areas due to their lightweight design, which offers a significant advantage in torque density, as illustrated in Fig. 1. Although higher reduction ratios can reduce motor weight and potentially improve torque density, current efficiency limitations prevent full realisation of this potential. Current high-ratio gearboxes can achieve peak efficiencies close to 80%, but under varying robotic cycles with sub-nominal torques, their average efficiencies can drop below 50%.

This has stimulated research into lightweight, efficient actuation in robotics, leading to innovations like incorporating elastic elements, clutches, and other mechanisms to improve energy efficiency, optimising motor torque density, and developing new gearbox concepts. Beyond robotics, other modern technologies, including wind turbines, electric vehicles, and hybrid cars, also demand lightweight, efficient motorisation.

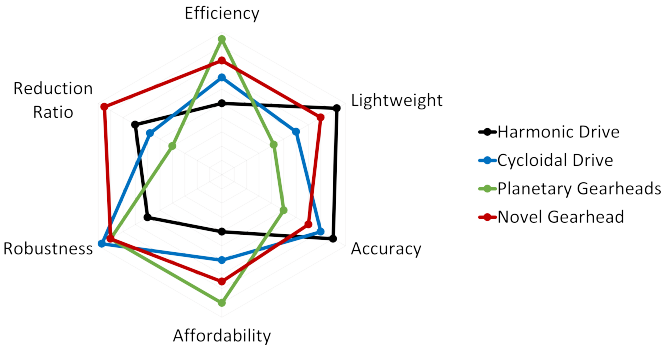

Fig. 1: Comparing important metrics for HCR of high-ratio gearbox technologies

Previously, we have presented a novel high gear ratio transmission concept which can obtain gear ratio over 200:1 in a compact way [2]. The Wolfrom-based planetary gear traditionally suffers from high energy losses due to a phenomenon called *Rolling power*. By means of modifications in the configuration and meshing efficiency optimisations, it was shown that the *Rolling power* could be greatly decreased.

Fig. 2: Novel high gear ratio transmission.

In this poster we want to present our latest results of the actuator we have designed for HCR which has a total gear ratio of 222:1 and is designed for a repeatable torque of 80Nm.

References

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