Three-Axis Power Synthesising Transmission for Walking Robots

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1 Introduction

Legged robots consist of complicated parts, such as body and leg structures, actuators, gearboxes, power supply and controllers. The mass of the legged robot, its actuating output, and the overall power density have a large influence on the robot's dynamic performance. For example, a low mass and greater motor power can enable the robot to jump and mitigate impacts [1]. As such, a variety of requirements are present when developing the mechanical structure of legged robots. However, the mass and motor power is typically inversely related, as a more powerful motor also requires more windings, structural and magnetic material. A greater torque output and payload capacity can be obtained by implementing speed-reducing gearboxes, but at the cost of additional mass and lowering the movement speed [1]. Reducing the robot legs' mass can further improve the robot dynamics, as the movement inertia is minimised. As such, it is advantageous to utilise a variety of methods to minimise leg mass. For example, topology optimisation can minimise the mass of the leg structure while maintaining strength [2]. The leg mass can be further reduced by moving the motors and gearboxes from the leg structure to the robot body. A transmission can then be used to transfer the motor power to the specific leg joints. However, while it is possible to transfer motor power to a joint with belts [1] or four-bar mechanisms [3], it then becomes increasingly difficult to channel multiple degrees-of-freedom, as the transmissions for the later joints have to pass over the previous ones. As four- and six-legged robots typically have legs with 3 degree-of-freedom (DOF), the transmission then needs to channel the movement and power from three motors. Hence, in this study, we propose a new motor transmission that removes the mass of all mechatronic components from the leg structure and combines, increases and channels the motor torques to the leg joints. We present a theorised mechanical model of the transmission and formulate the position relationship between the motors and joints.

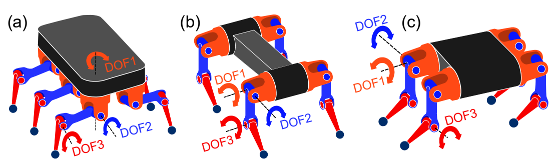

Figure 1: Three mounting styles with DOF1 performing either hip (a) internal/external rotation, (b) flexion/extension, or (c) abduction/adduction.

2 Transmission structure

Three 1,500 watt brushless DC motors (01) controlled by an in-house developed motor controller (02) were selected to power the transmission. The motors, controllers and subsequent gear components are connected to the housing (03). Spur gears with 12 teeth of hardened steel (06) (Figure 2) are attached to the output axis of each motor. The input gears (06) and motor axes (08) surround three larger output gears (07) that share the same rotational axis and are coupled to the housing through bearings (11). All the output gears have 96 teeth, which results in an 8:1 speed reduction between each input and output gear. The larger output gears differ in bore size and flange patterns in order to connect with the subsequent components, like drive axes and bearings (11), bevel gears (09) (10), and leg components (04) (05). The first motor (M1) drives an output gear that rotates the leg's base (Figure 2-DOF1, red), which enables a variety of hip movements and strides (Figure 1). The second motor (M2) drives the spur gears, which actuates the femur segment (05) (Figure 2-DOF2, blue) through a set of bevel gears (09), which enables robot movements such as hip flexion/extension (Figure 1-a and c) or abduction/adduction (Figure 1-b). The third motor (M3) also drives both spur- and bevel gears (10) (Figure 2-DOF3, red). Subsequently, a linkage can be used to transfers the DOF3 rotation to flex/extend the knee joint (Figure 1). Hence, the transmission may help emulate an animal's motion by better matching its mass distributions [4].

3 Formulation of transmission

The transmission channels the power of the three base-fixed motors to the joints by overlapping gears with a similar gearing ratio (8:1). Except for DOF1, which is only powered by motor M1, the DOF2 and DOF3 are then influenced by motor movements related to the previous joints. With the specific rotational orientation (Figure 2), the joint movements can then be formulated as:

$$\Delta\theta_{DOF1} = -\frac{\Delta\theta_{M1}}{8} \quad (1)$$

$$\Delta\theta_{DOF2} = \frac{\Delta\theta_{M2} - \Delta\theta_{M1}}{8} \quad (2)$$

$$\Delta\theta_{DOF3} = \frac{\Delta\theta_{M3} - \Delta\theta_{M2} - \Delta\theta_{M1}}{8} \quad (3)$$

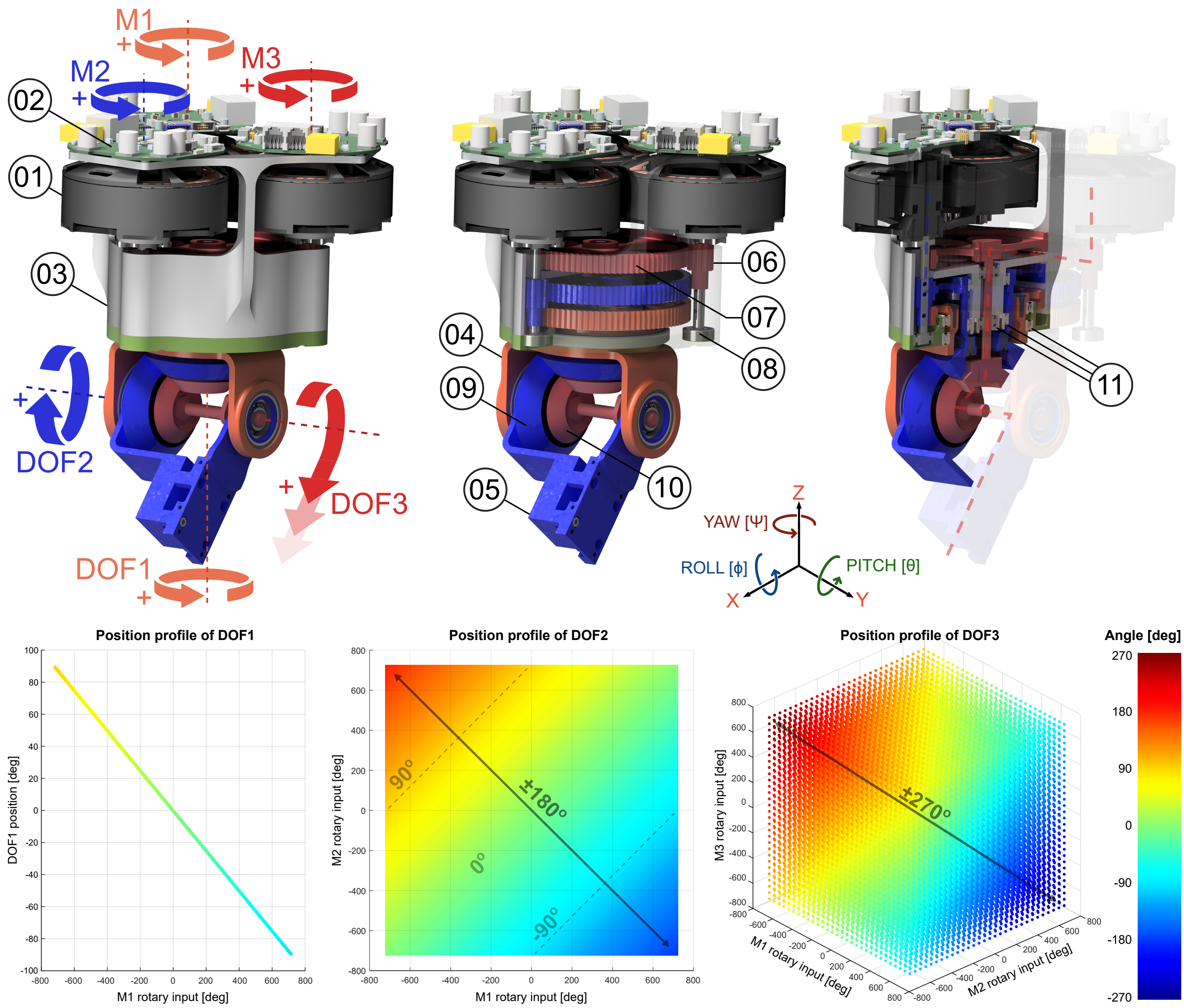

Figure 2: A motor transmission that reduces leg movement inertia and couples motors together by a speed-reducing spur (8:1) and bevel gears (1:1) that move the motors to the grounded base housing. From the base, three motors (M1, M2, M3) channels power to three joints: the base hip joint (DOF1), flexing/extending hip joint (DOF2) and the knee joint (DOF3). A combination of the motor movements actuates three leg DOF (1), (2), (3) shown in Figure 1.

where $\Delta\theta_{M1}$, $\Delta\theta_{M2}$ and $\Delta\theta_{M3}$ are the output position of the three motors, which is reduced by the gears by a factor of 8. Eq. 1 subtracts M1, as the spur gears inverses the rotation before reaching $\Delta\theta_{DOF1}$. Meanwhile, the bevel gears returns the rotational direction of $\Delta\theta_{DOF2}$ and $\Delta\theta_{DOF3}$.

4 Conclusion

The transmission design and position equation indicate that it can channel power from three base-fixed motors to three leg joints, where the three motors' combined rotation determines the joint movements. The transmission ability to reduce the leg mass may help better emulate animals' motion. We suggest that future studies further investigate the transmission's capabilities as a physical prototype.

5 Acknowledgements

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