Robotic Leg Design having Energy Recovery Capability

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Abstract—This article reports a backdrivable leg design that has small clearance and friction and meets the torque requirement for human walking. Preliminary testing data show that the leg can stand up on its own by tracking a predefined trajectory that is obtained in a Webots simulation that handles well closed-loop chain dynamics. This design enables future energy recovery operation of the bipedal robot system using a customized four-in-one motor drive system.

I. Balance between Backdrivability and Power

In terms of friction, the ball screw is like a bearing rather than a gearbox, which makes a perfect fit to realize a quasi-direct drive actuator [1] that is backdrivable and allows two way flow of kinetic energy. A four-bar mechanism is further adopted to keep a reasonable dynamic transmission gain to the output joint. The resulting actuator is powerful to make a leg prototype to stand up carrying a total weight load of 48.7 kg (including the leg), and higher weight load breaks the 3D printed shank part.

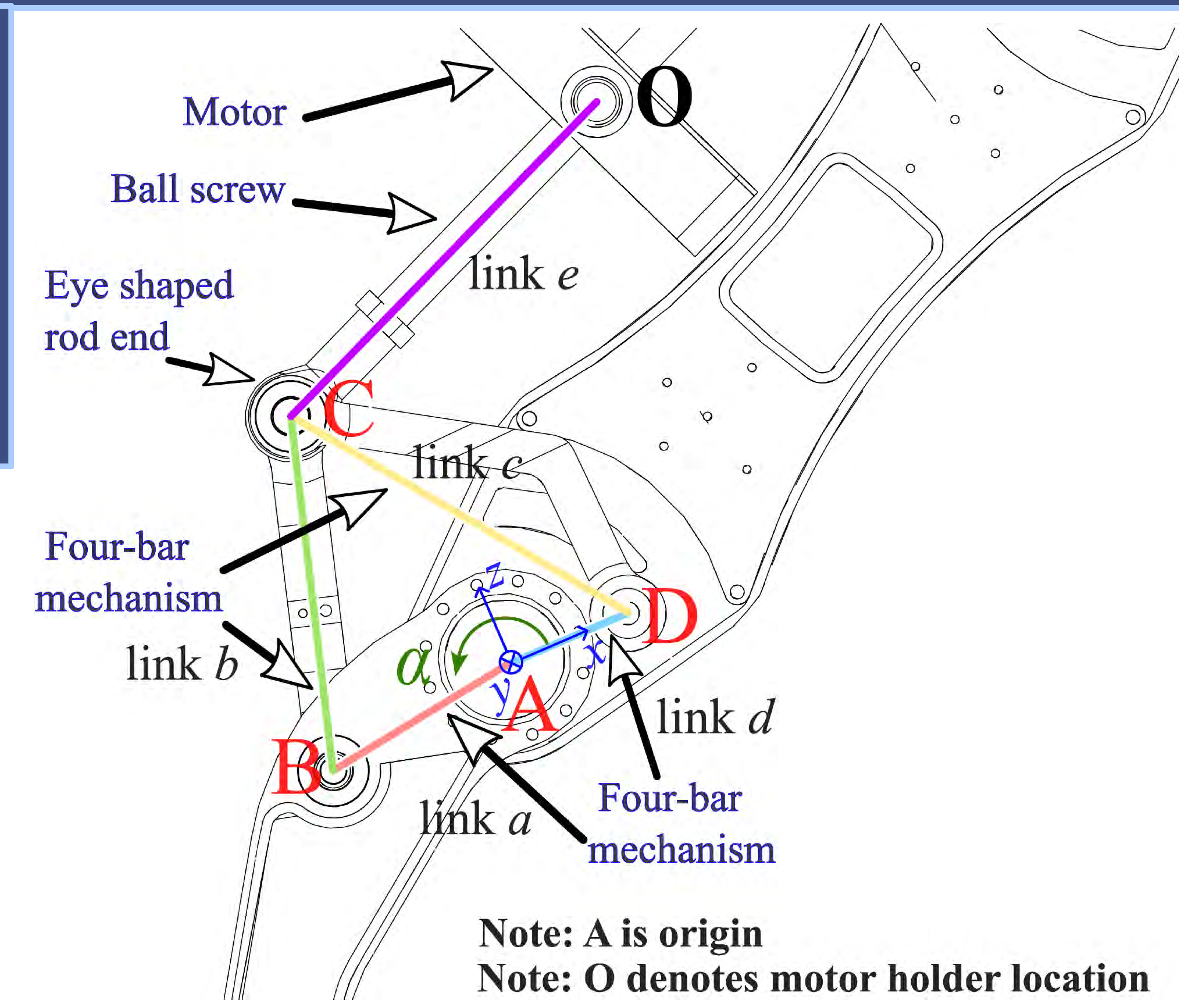


Fig. 1: The knee actuator of the robotic leg.

II. Human Walking Data

The human walking data of adult in [7] has been utilized to check the powertrain is strong enough to support human like walking.

It is found during optimization that higher motor location leads to reduction in motor torque requirement.

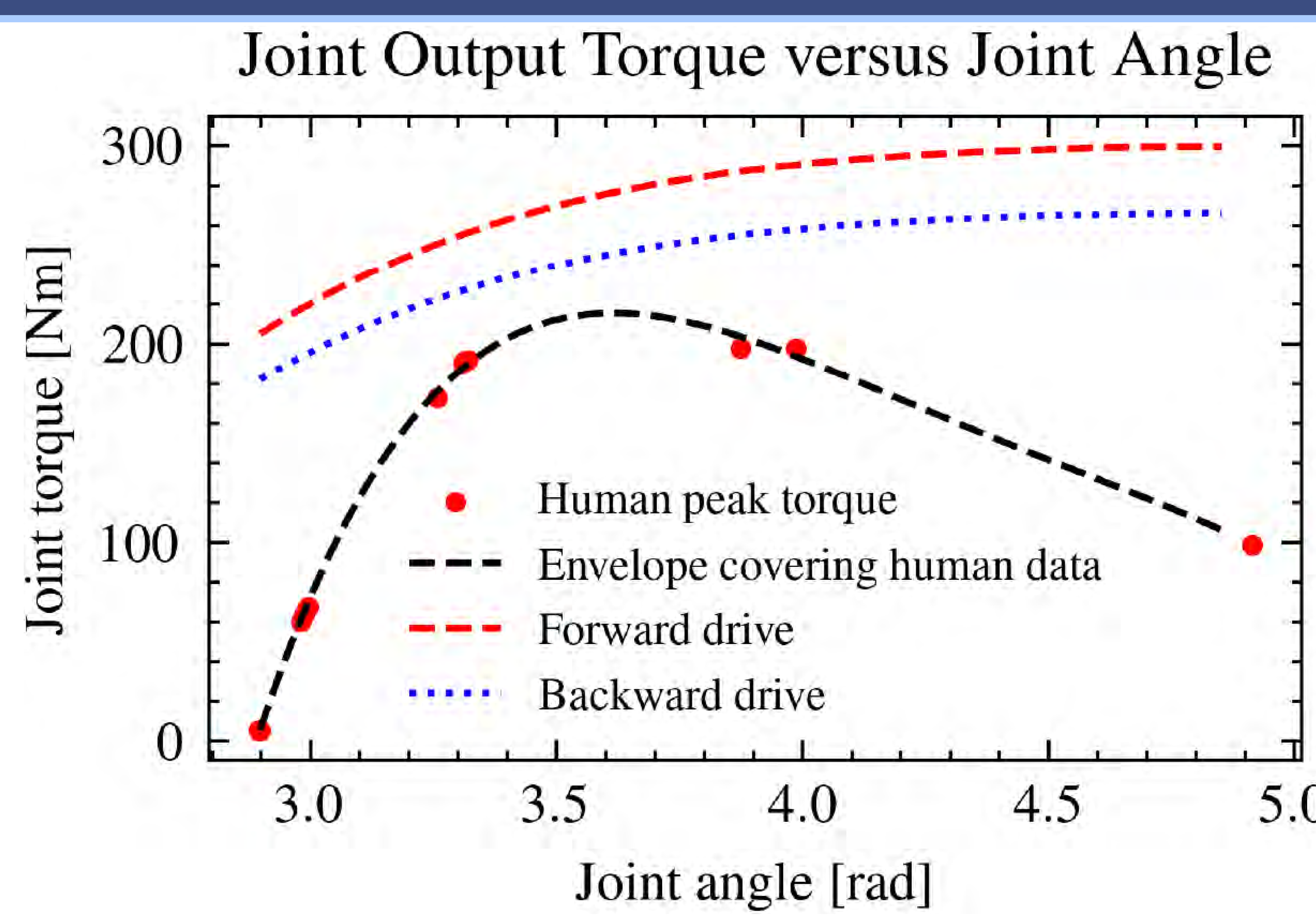
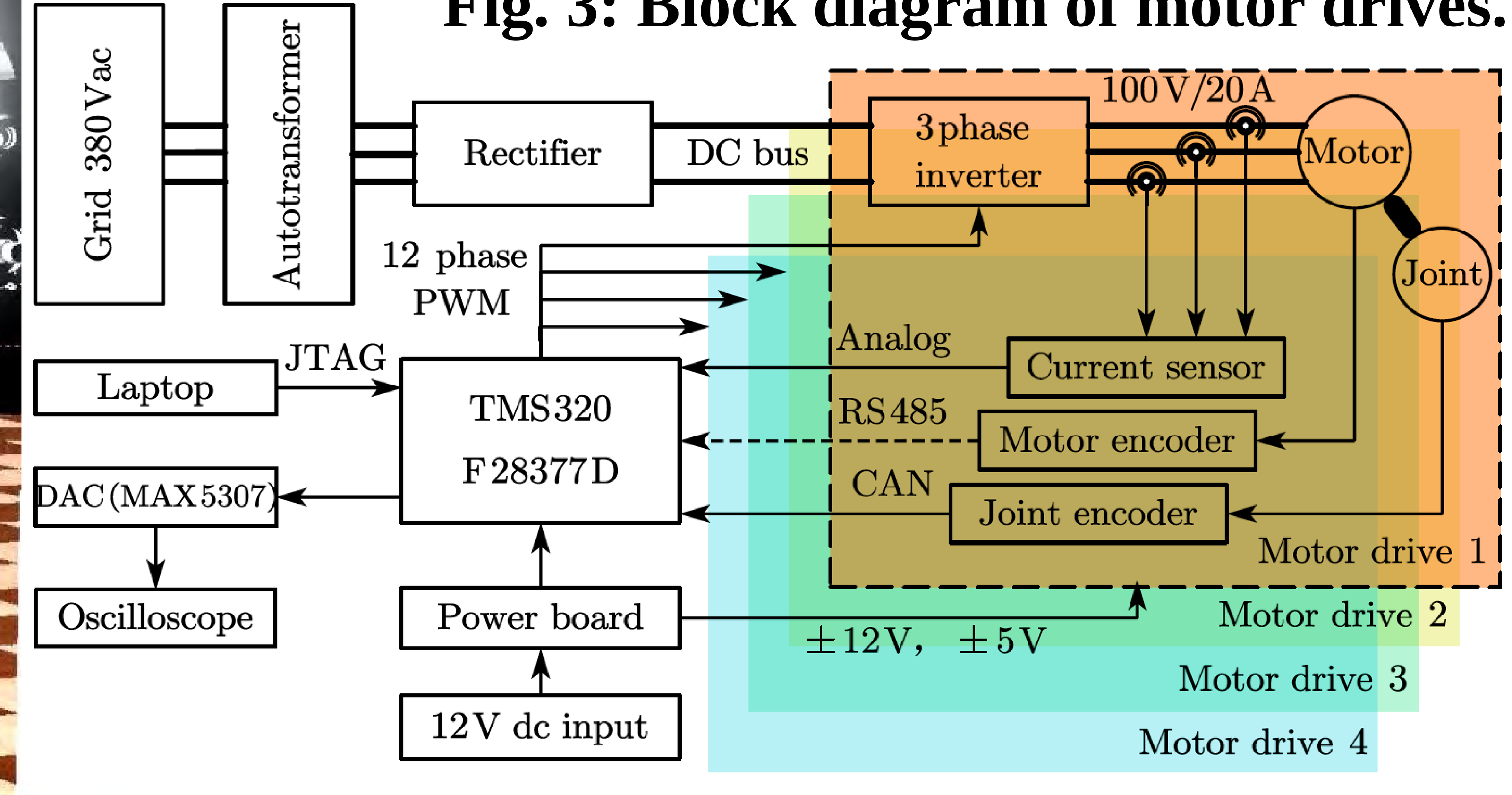


Fig. 2: Comparison between linear actuator joint output torque and the envelope of the peak joint torque of a real human while walking.

III. Self-built Motor Drives

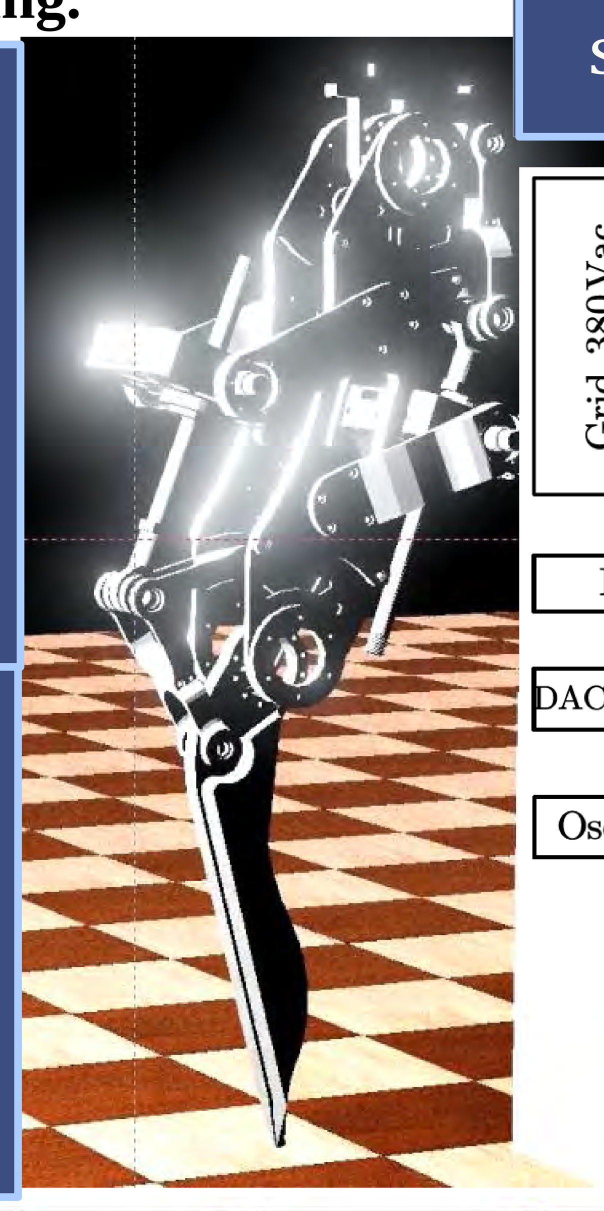
The motor drives are controlled by a 6 phase inverter receiving gate signals from a digital signal processor, as detailed in Fig. 3.

Fig. 3: Block diagram of motor drives.



IV. Simulation of Closed Loop Chain

The simulation of robot system is performed through Webots, which offers the node called “SolidReference” for supporting closed-loop chain dynamics without needing manual parameter adjusting. The URDF file of the leg is translated into a “PORTO” format2, which implements closed-loop chain dynamics by changing node type.



V. Testing

By following the predefined trajectory, the leg prototype is able to stand up with weight load. Waveforms of trajectory tracking of the two joints and phase current are shown in Fig. 4, which corresponds to an elevation of 12 cm in height as annotated in Fig. 5.

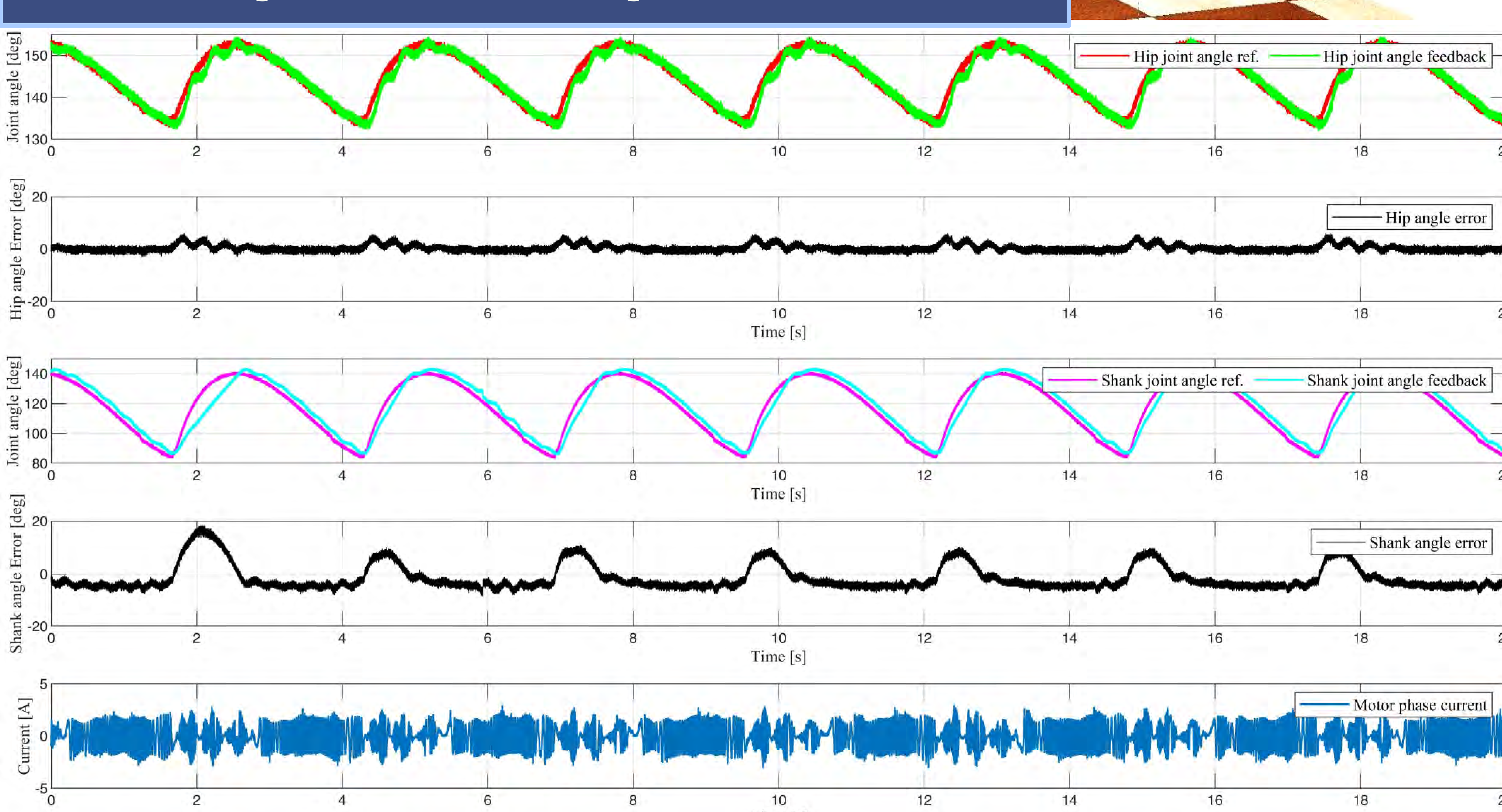


Fig. 4: Two joints motion tracking test results.

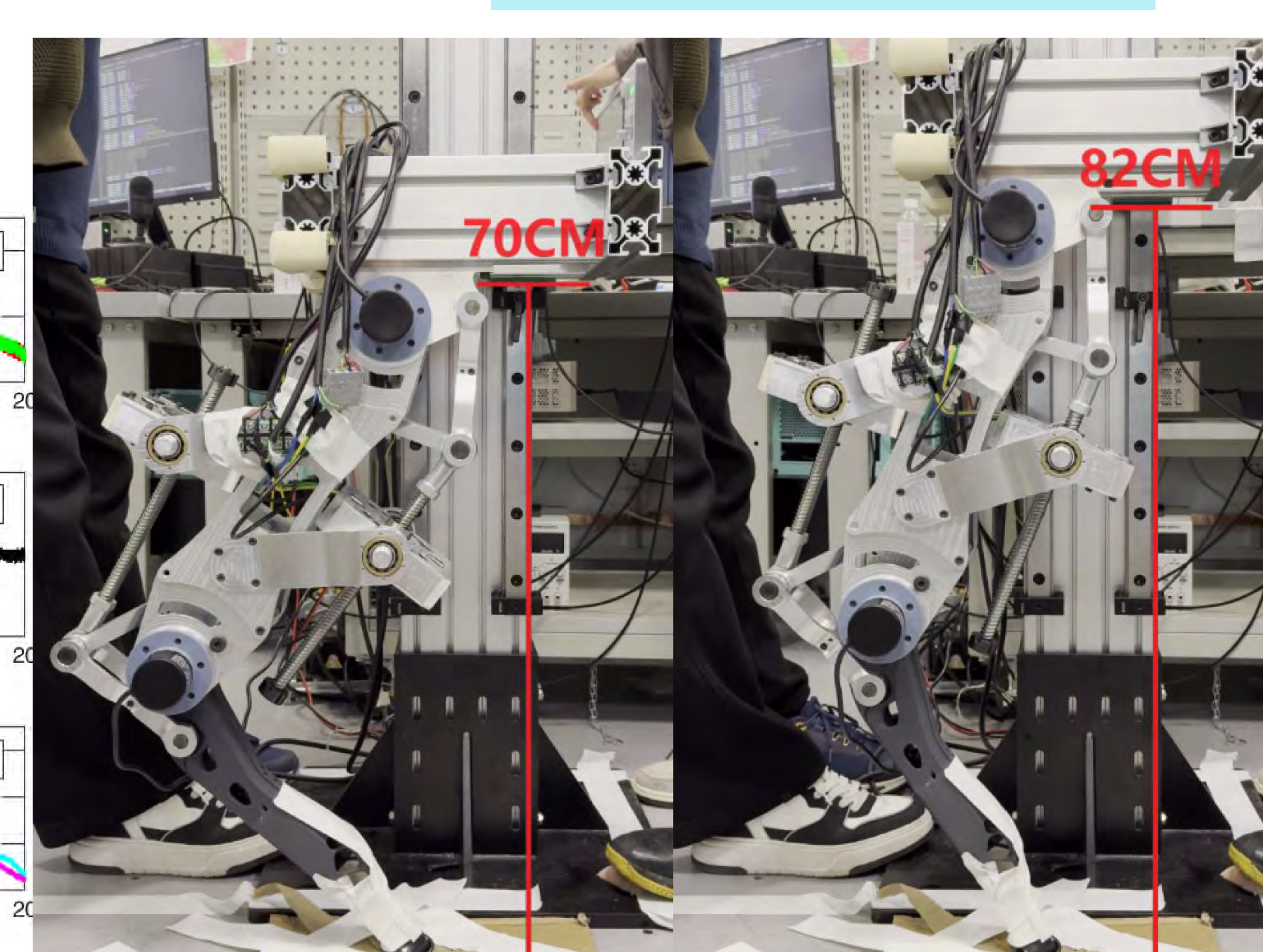


Fig. 5: Sequential snapshot of trajectory tracking.

References:

[1] M. E. Carney, T. Shu, R. Stolyarov, J.-F. Duval, and H. M. Herr, “Design and preliminary results of a reaction force series elastic actuator for bionic knee and ankle prostheses,” IEEE Trans. Med. Robot. Bionics, vol. 3, no. 3, 2021.

[7] T. J. van der Zee, E. M. Mundinger, and A. D. Kuo, “A biomechanics dataset of healthy human walking at various speeds, step lengths and step widths,” Sci Data, vol. 9, no. 1, 2022.