Design and Preliminary Evaluation of a Pediatric Exoskeleton

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Abstract

Cerebral palsy and spina bifida are two of many neurological and developmental disorders that occur in children and can result in gait impairments. Rehabilitation techniques traditionally use overground gait trainers with the aid of parallel bars, walkers, etc. or treadmill-based gait trainers for longer sessions. However, in these sessions, therapists manually guide the patient's legs as they walk which can be exhausting and limit the duration of a training session. A lower-limb exoskeleton can help alleviate this and other drawbacks by providing torque to the patient's joints. This poster describes the first stages of hardware development and evaluation of an exoskeleton design for pediatrics.

Design Requirements

- The pediatric exoskeleton presented here is designed to provide both gait rehabilitation and assistance for children between the ages of 6 and 11 years with some degree of gait impairment.
- The exoskeleton must consider child growth and wide range in height and weight for these children, which averages around 119–150 cm and 23–48 kg, respectively [1]. In addition, the device should account for anatomical or physiological abnormalities that may be present in the target user base.
- This will be accomplished by developing an exoskeleton that can provide torque to the hips and knees of the subject, which has been shown to be useful at least for those with paraplegia or gait impairment from spinal cord injury or stroke in adults [2].
- The actuators in the exoskeleton should provide sufficient range of motion (ROM), joint velocity, and joint torque. Typical healthy gait is used for can be found in Fig. 1, with expected values tabulated in Table 1 based on a 110 steps/minute cadence [3].

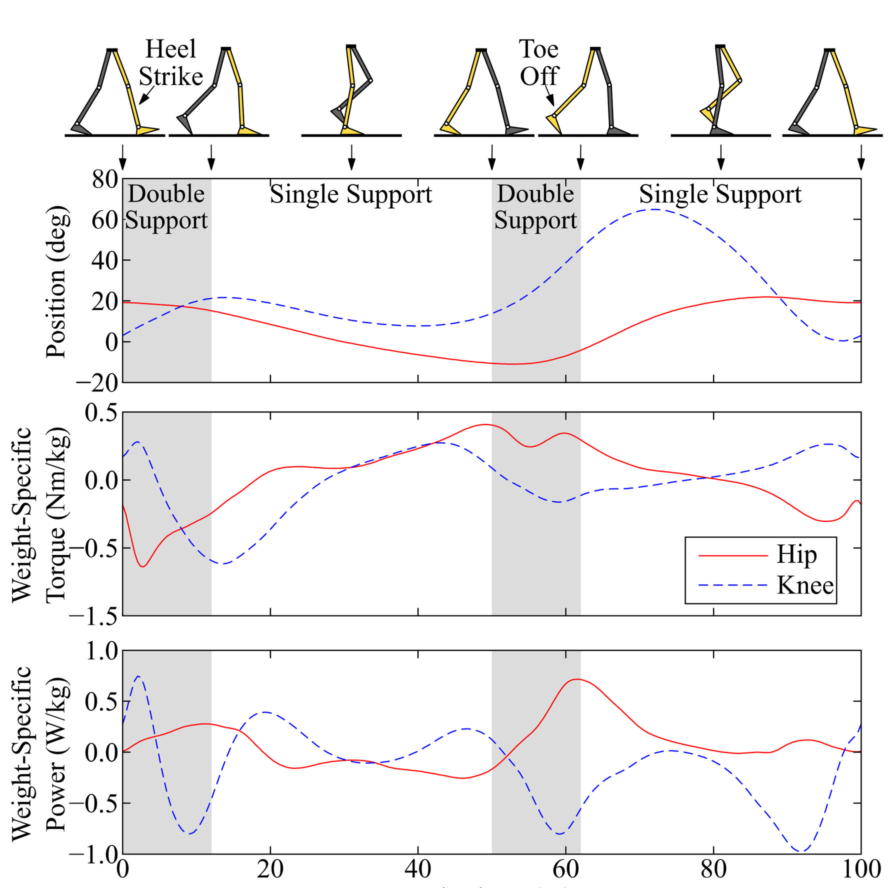

Figure 1: Healthy gait

Table 1: Design requirements

	Hip	Knee
Range of motion (deg)	−11 to 22	0 to 65
Velocity (deg/s)	−82 to 159	−369 to 312
Peak torque, 11 years (Nm)	−28.5 to 19.2	−29.2 to 13.3
Peak power, 11 years (W)	−12.1 to 33.9	−46.4 to 35.4

Actuator Design

- The same actuator design is used for both the hips and knees for simplicity in design.
- The actuator is electrically powered using brushless DC motor with a rated nominal operating power of 70 W. This should satisfy the peak power requirements of 47 W at the knee and 34 W at the hip, even after frictional losses.
- The supplied torque passes through a three-stage toothed-belt transmission with a total speed reduction ratio of 40.6:1. The tension in the belts can be changed by adjusting the shaft locations with screw-adjustment incorporated in the design.
- The actuator output, with an ideal transmission, has a stall torque of 35.7 Nm, continuous torque of 5.4 Nm, and a nominal speed of 375 deg/s, which should be sufficient to meet the aforementioned torque and speed requirements.
- A magnetic angle sensor at the output is used to measure joint angle and Hall effect sensors in the motor are used to measure motor velocity. These can be used in feedback control.

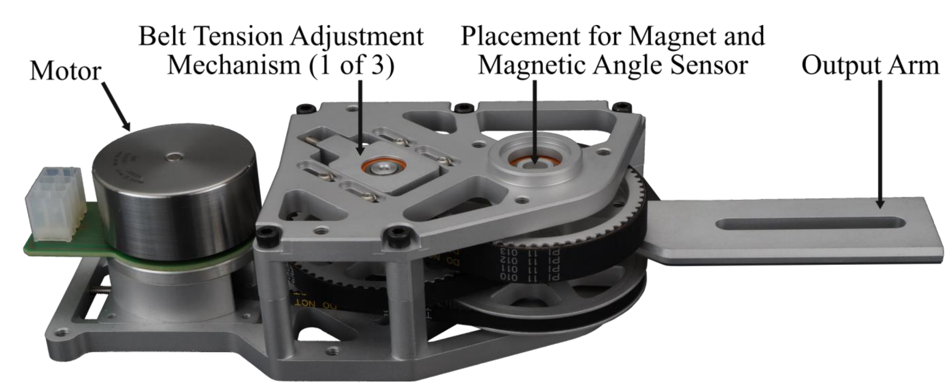

Figure 2: Actuator for the pediatric exoskeleton

Evaluation of Actuator Capabilities

- First, the unloaded speed capabilities was evaluated by running the actuator unhindered up to 480 deg/s in both directions.
- Second, static output torque capabilities was evaluated by incrementally increasing current with a force gauge statically holding the output. Results in Figure 3 show max. continuous torque of 4.2 Nm and max. peak torque of 17.2 Nm. The force gauge was released until motion, measuring breakaway torque. The half-difference estimates static friction as about 1.0 Nm.

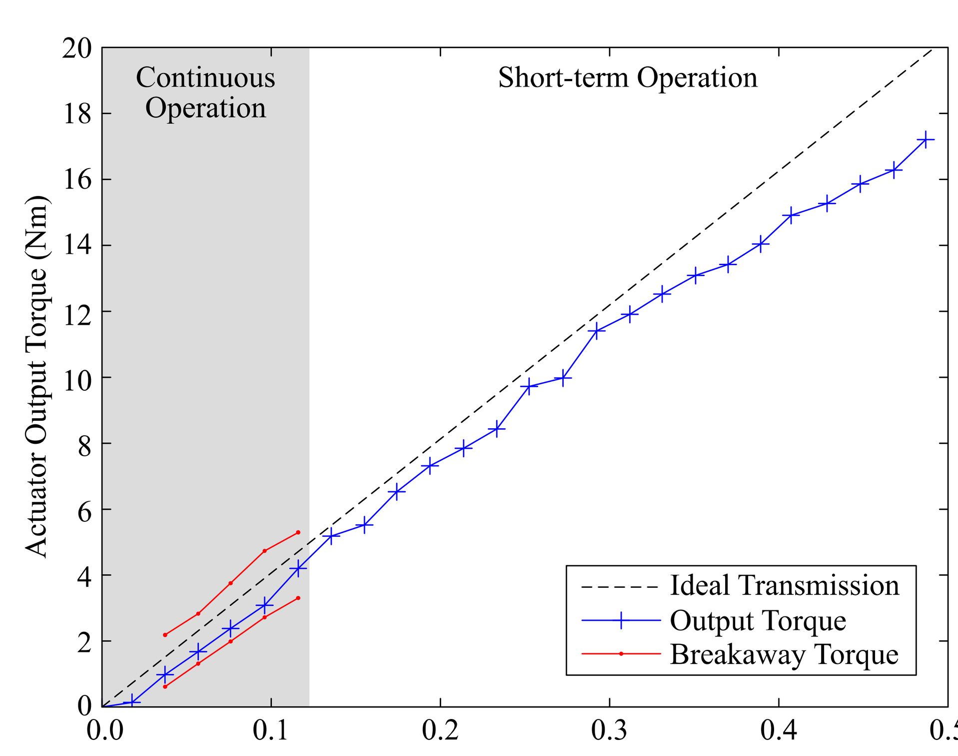

Figure 3: Actuator output torque vs. motor torque

- Third, non-static friction was measured by running the motor at various constant speeds up to 400 deg/s in both directions. Current measurements did not vary significantly, suggesting Coulomb friction dominates viscous friction at about 1.0 Nm.

Experimental Gait Tracking Results

- A testing exoskeleton and a dummy were developed based on an average 8 year old [1], [4], shown in Figure 4, for early evaluation of the actuators in experimentally tracking gait.
- Two experiments are conducted. First, the dummy is left unloaded, with a thigh mass of 1.2 kg and a shank mass of 1.2 kg. Second, the dummy is loaded with masses and has a thigh mass of 3.2 kg and a shank mass of 2.2 kg.
- A proportional-derivative control law is used for gait tracking. The same controller gains are used for each case, tuned based on the loaded case.
- Experimental results can be found in Figure 5 and Table 2.

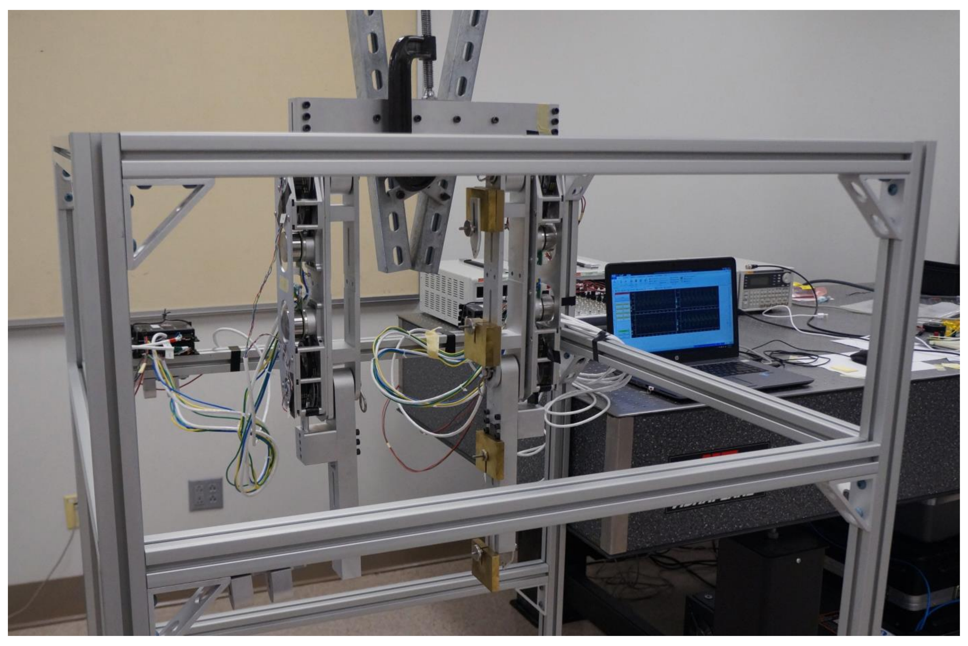

Figure 4: Experimental test setup for gait tracking

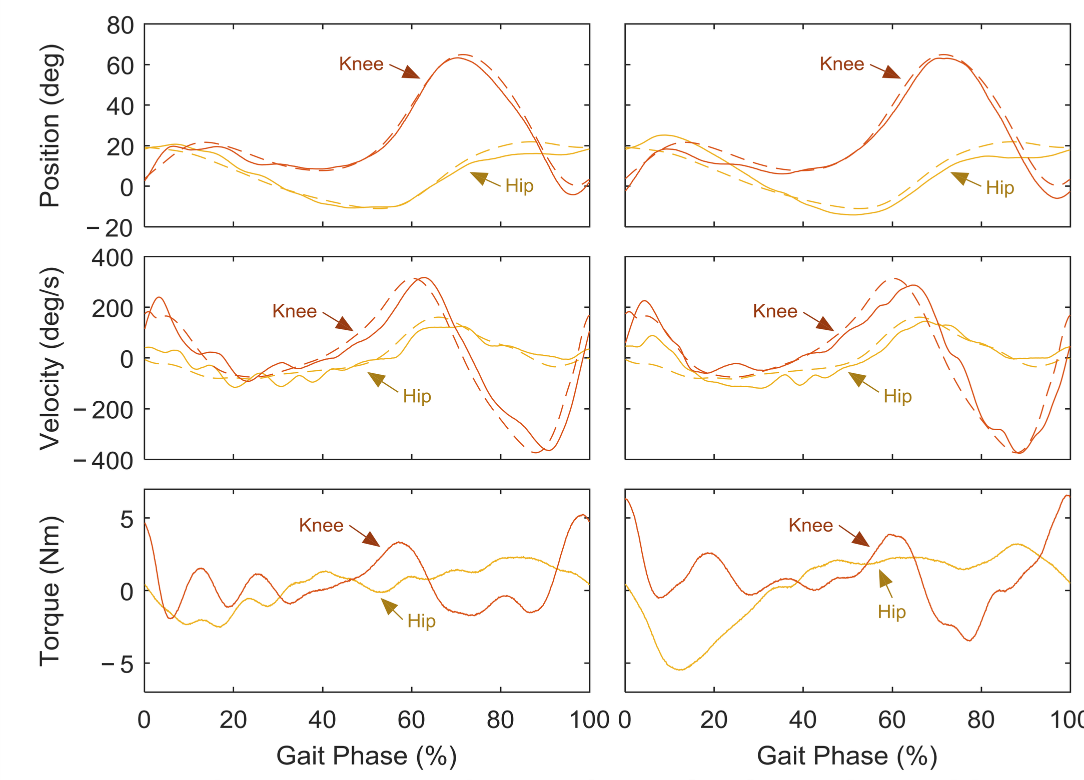

Figure 5: Experimental results for gait tracking

Table 2: Position error, and peak and RMS torque

	Unloaded Case		Loaded Case	
	Hip	Knee	Hip	Knee
Position RMS error	3.0 deg	2.7 deg	5.1 deg	3.9 deg
Peak torque	2.5 Nm	5.3 Nm	5.5 Nm	6.6 Nm
RMS Torque	1.4 Nm	1.8 Nm	2.6 Nm	2.3 Nm

Conclusions

- Actuator capabilities experiment shows adequate operation of 480 deg/s and can provide at least 17.2 Nm peak torque.
- Actuators successfully drove a dummy to track healthy gait pattern with a position RMS error of 5.1 deg in the worst case.
- Peak and continuous torque was 6.6 Nm and 2.6 Nm. Larger gains could be used.
- Future work entails work with a device ready for subjects. See figure to the right.

Acknowledgements & References

This research was funded in part by the Parker Hannifin Corporation. The actuator is intellectual property of Cleveland State University with patent pending. The work described here is based on [5].

[1] C. D. Fryar, Q. Gu, and C. L. Ogden, *Anthropometric reference data for children and adults: United States, 2007-2010*, vol. 252. Hyattsville, MD: National Center for Health Statistics, 2012.

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