CPS: Medium: Collaborative Research: User and Environment Interactive Planning and Control of Artificial Lower Limbs for Resilient Locomotion

Hartmut Geyer, CMU, and Hao Su, CUNY

contacts: hgeyer@cmu.edu; hao.su@ccny.cuny.edu

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Creating Biomedical Technologies to Improve Health

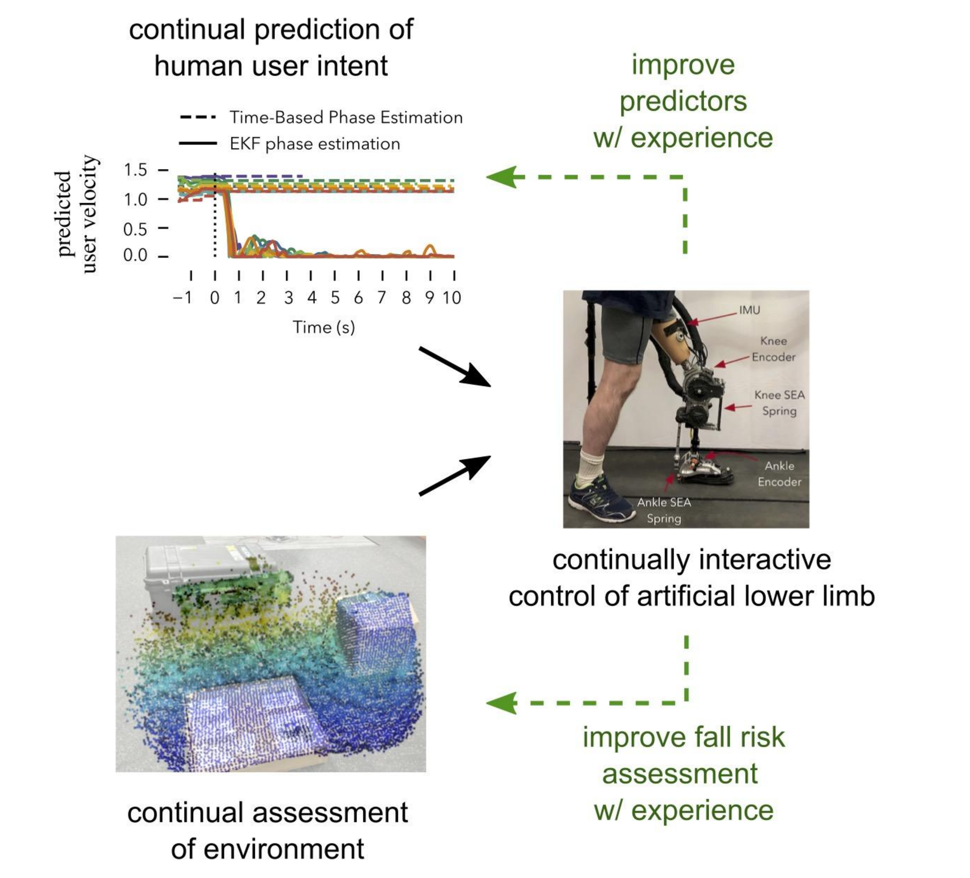


Figure 1. Overview of approach.

Control of artificial limbs will need to break away from predefined motions

Today, even normal locomotion is difficult to master for people who depend on prostheses or exoskeletons for mobility and rehabilitation, and there is a clear understanding in the wearable robotics community that a break away from predefined motions will be required to overcome this limitation.[1]

Embracing this view, our project pursues a cyber-physical approach, in which the artificial limb takes advantage of rich sensory information to continuously reason about and adapt its behavior to both the user and the environment with the goal of improving mobility with artificial lower limbs (**Fig. 1**).

Project explores algorithms and hardware for continually interactive control of artificial legs

The specific objectives of the project are to

(1) establish user and environment interactive control of artificial lower limbs,

(2) develop multi-sensory and highly dynamic prototype exoskeletons and prostheses that enable its sensor-rich and data-intensive implementation, and

(3) evaluate the resulting controller performance in human subject experiments.

Currently in early stage, focusing on objectives 1 and 2.

Reasoning about environment combines leg SLAM with model of future leg motion

For building knowledge about the environment, we investigate ways to perform SLAM with depth-cameras attached to lower limb (**Fig. 2-a**). Challenges to stable point cloud registration include fast limb motion, high landing impacts, and ill-defined objects temporarily in the field of view.

For using this knowledge, we currently focus on predicting (i) likely foot placement goals and (ii) corresponding safe swing leg motions (**Fig. 2-b**). Challenges include performing nonlinear optimization of future leg motions within the first 50ms of swing.

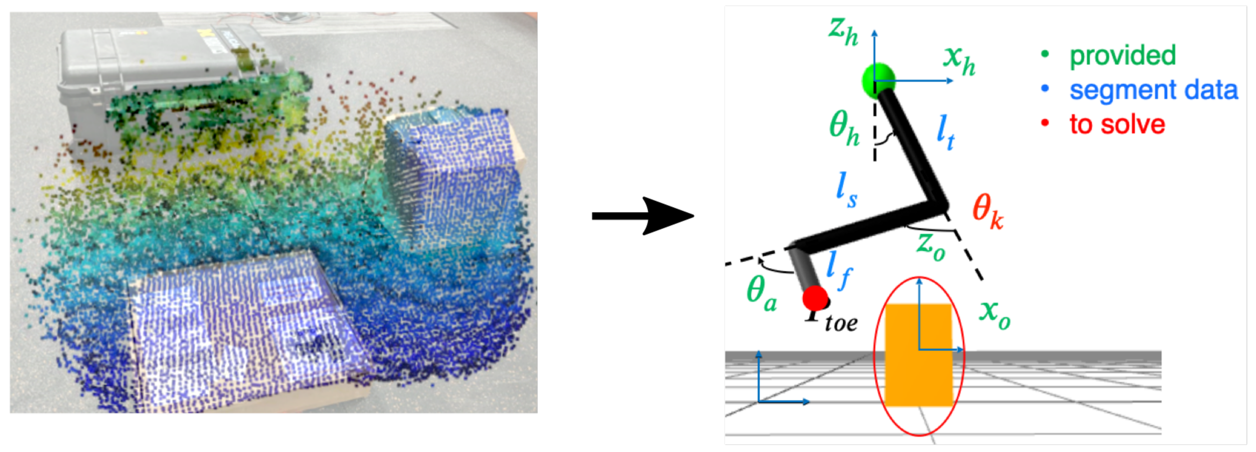


Figure 2. Example integration of reasoning about environment.

Reasoning about user intent uses data-driven learning to predict human-desired limb behavior

Different learning algorithms have been proposed to predict behavior of human actors including VAEs, CNNs, LSTMs, and CRBMs. We currently investigate which of these adapts to the specific case of predicting future leg behavior not only for steady gait[3] but also for transitory motions such as obstacle encounters, intentional step corrections, and gait transitions (**Fig. 3**).

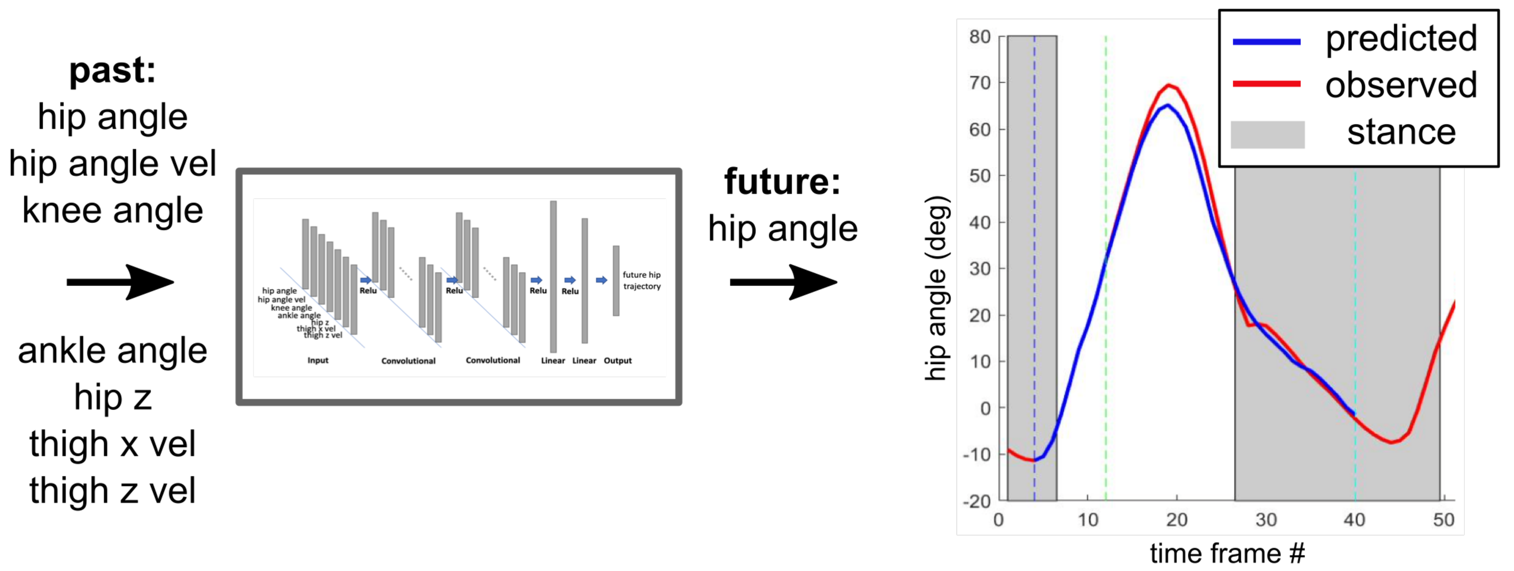


Figure 3. Prediction of human-desired leg behavior.

Quasi-direct drive actuator design enables high performance of artificial lower limbs

- Quasi-direct drive leading to actuation paradigm shift (**Fig. 4**)
- High bandwidth and compliance[4] actuator (**Fig. 5**)
- High performance artificial lower limbs (**Fig. 6**)

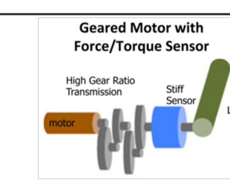
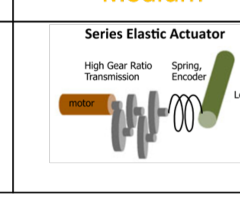
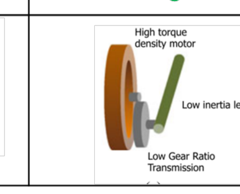
	Geared Motor with Force/Torque Sensor	Series Elastic Actuator [MIT1999]	Quasi Direct Drive Actuator [Su2019]
Compliance	Low	Medium	High (0.4 Nm)
Bandwidth	High	Low	High (62.4 Hz)
Efficiency	Low	Medium	High
Actuation paradigm			

Figure 4. Our actuator achieves high compliance and high bandwidth.

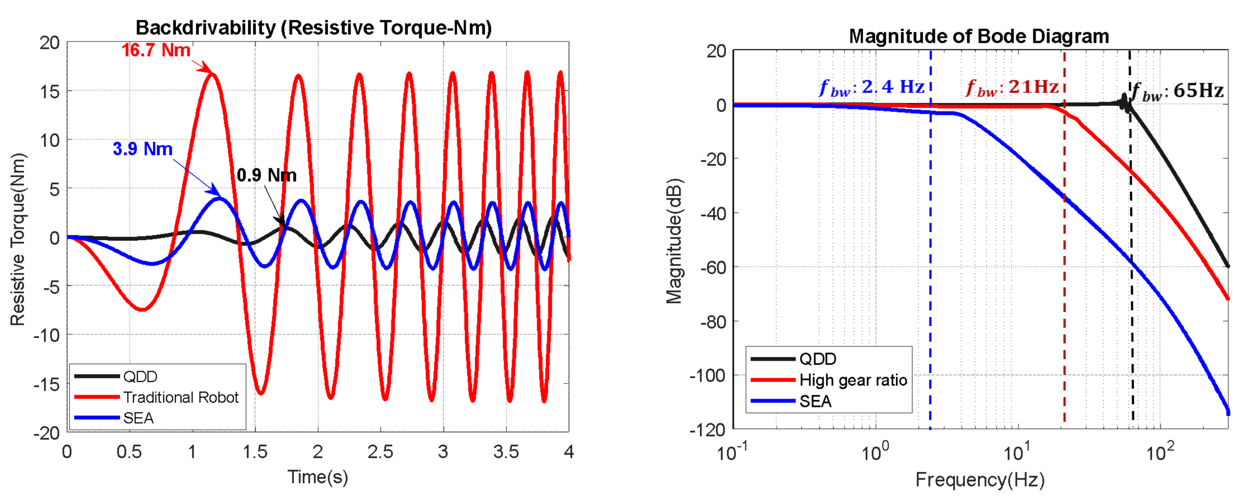
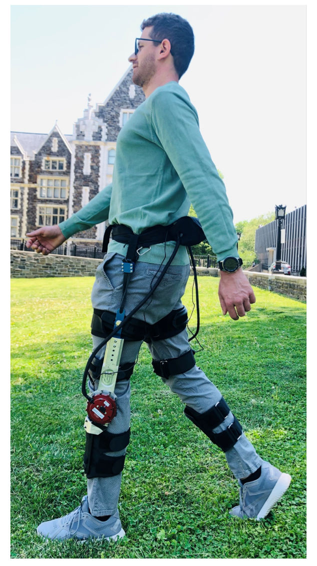


Figure 5. Demonstration of high compliance and high bandwidth with our high-performance exoskeletons.



	Knee exoskeleton	Knee-ankle prosthesis
Motor Torque	2.2 Nm	3 Nm
Motor Speed	1500 RPM	2000 RPM
Output Torque	40 Nm	216 Nm
Output Speed	16.2 rad/s	11.6 rad/s
Range of Motion	130 deg	130 deg
Gear Ratio	6:1	36:1
Unilateral Weight	2.4 kg	3.4 kg

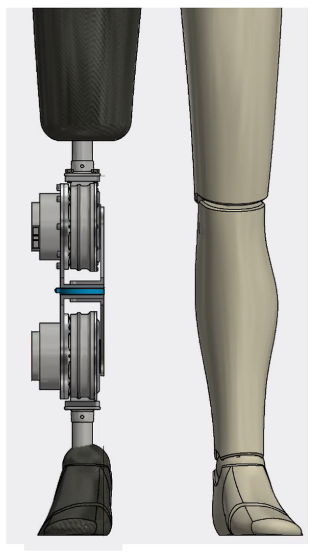


Figure 6. Specs of our high-torque density exoskeleton and prosthesis.

References

1: Tucker et al, J NeuroEng & Rehab 2015; 2: Howell et al, IEEE IROS 2019
3 Su & Gutierrez-Farewik, Sensors 2020; 4: Yu et al, Trans. on Mechantronics 2020