Human Cyber-Physical Systems

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CEEM Design and Control

This topic focused on the design, real-time interfacing and control of Cyber-Enabled Exercise Machines (CEEMs). We worked on two prototypes to host our control and estimation algorithms: a powered rowing machine and a four degrees-of-freedom (dof) robot designed for the upper limbs. The powered rowing machine can be programmed with arbitrary impedance at the user handle and is capable of eccentric loading. Conventional rowing machines are uncapable of tension forces during the return stroke of the rowing exercise, precluding eccentric loading. Motion capture studies were conducted to study the rowing exercise with fully instrumented conventional and powered rowing machines. In addition, metabolic data were recorded. Figures 1 and 2 show testing conducted with the conventional and powered models. Studies included accurate emulation of a conventional air resistance rower and tests with other forms of impedance.

Figure 1: Motion capture testing of rowing with fully-instrumented conventional machine

The 4-dof robot, dubbed CSU4OptimX, has two independent arms rotating around two mutually perpendicular, intersecting axes. As a result, each end effector moves on a geodesic circle. Such 3D paths offer opportunities to perform training motions for the arms against programmable resistances. The robot is fitted with motion and torque sensing on each axis. The data acquisition and control interface also collects EMG data and performs filtering. It also hosts the low-level

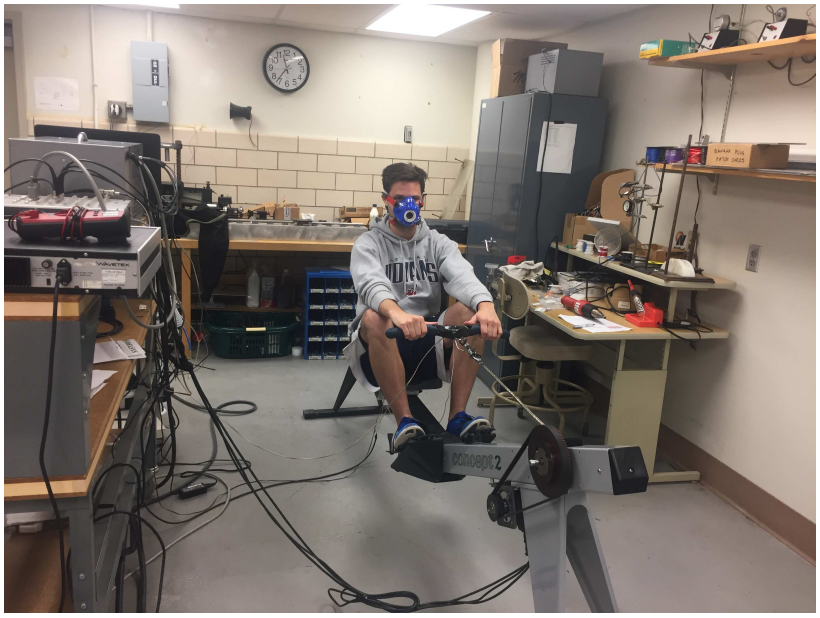

Figure 2: Lab testing of powered rowing machine

machine control algorithms and self-optimization training algorithms under study. Figures 3 and 4 show the device used for pilot tests.

The low-level machine controller is a robust impedance algorithm developed with sliding mode and impulse-momentum concepts. We also put efforts on the design and control of compliant, variable-stiffness and energy-efficient actuation systems for human-interacting machines such as powered exoskeletons and force augmentation devices.

1. Rowing machine design and control: [4, 2, 7, 3, 10, 9].
2. Robust impedance control with sliding modes and impulse/momentum emulation: [8, 1].
3. Energy-efficient variable-stiffness actuators for human-machine interaction: [5, 6]

References

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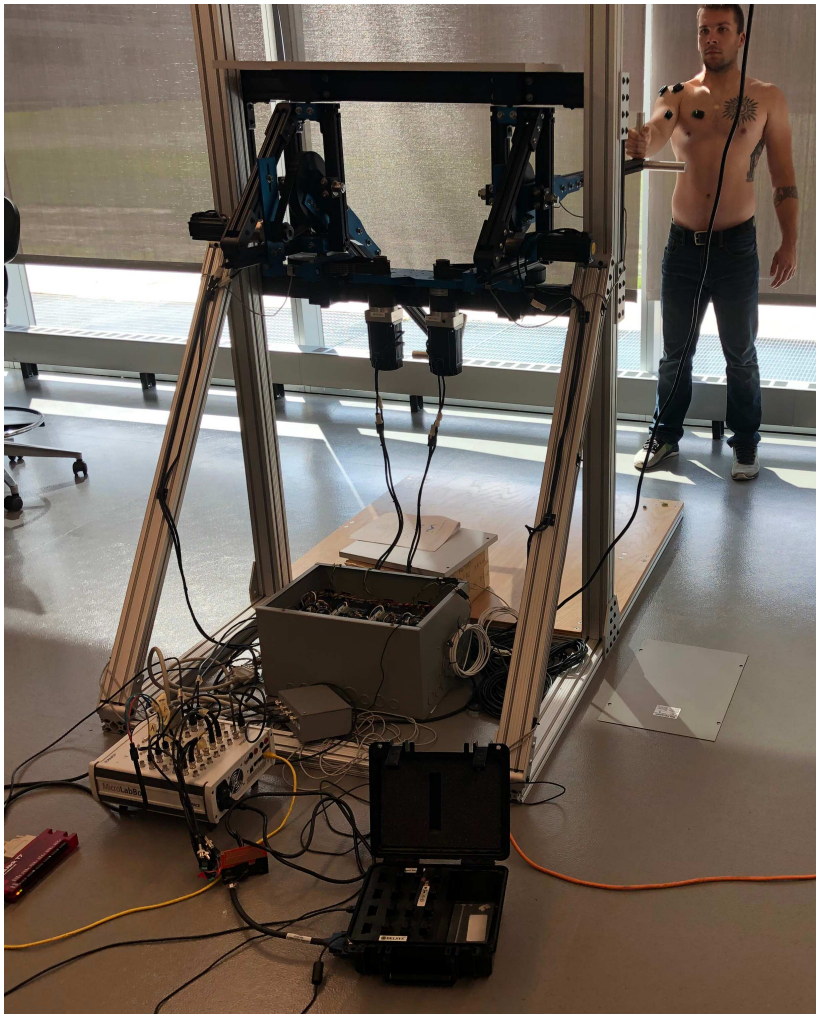

Figure 3: CSU4OptimX robot

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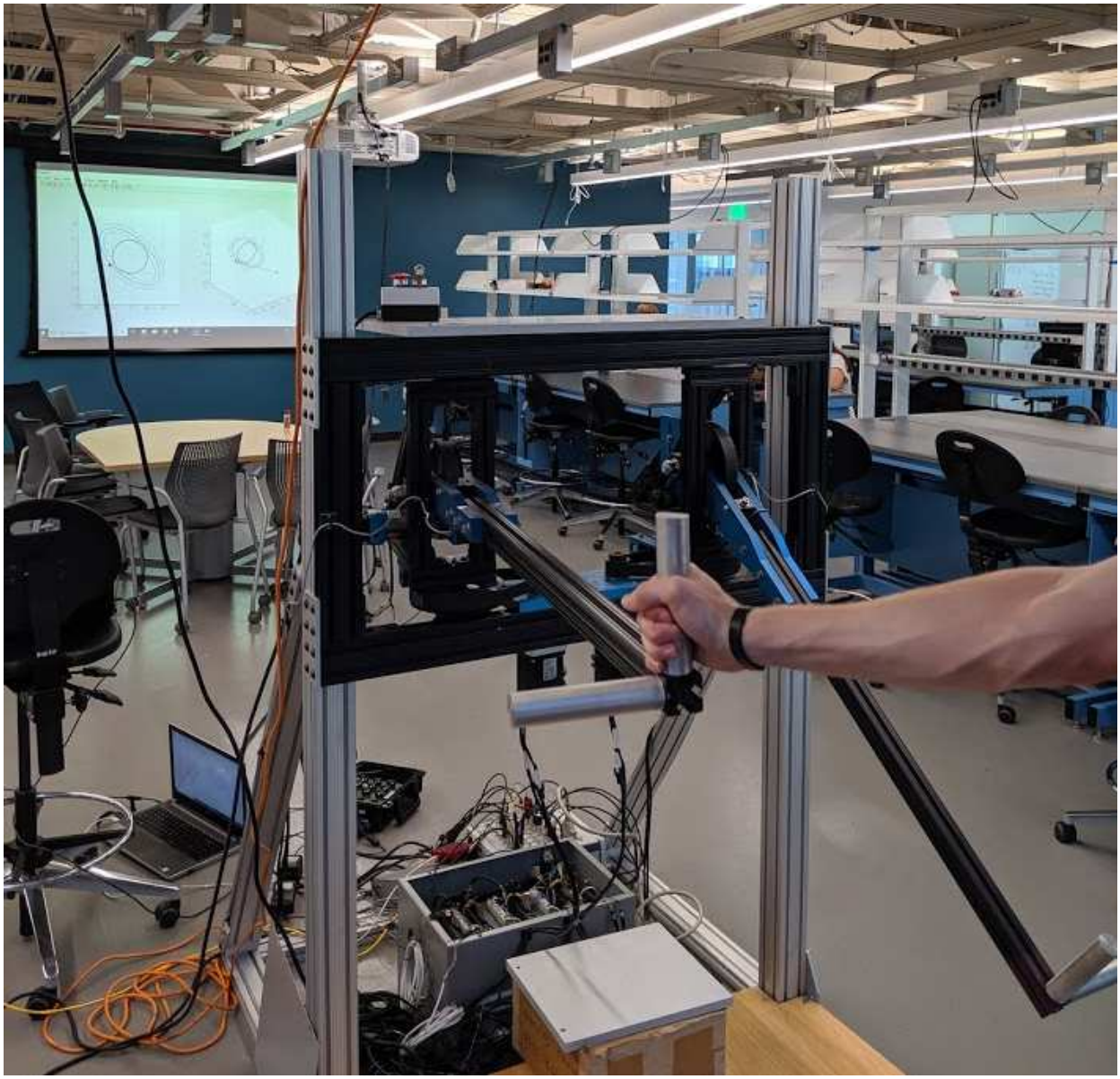

Figure 4: CSU4OptimX robot and graphical interface