NRI: FND: Natural Power Transmission through Unconstrained Fluids for Robotic Manipulation

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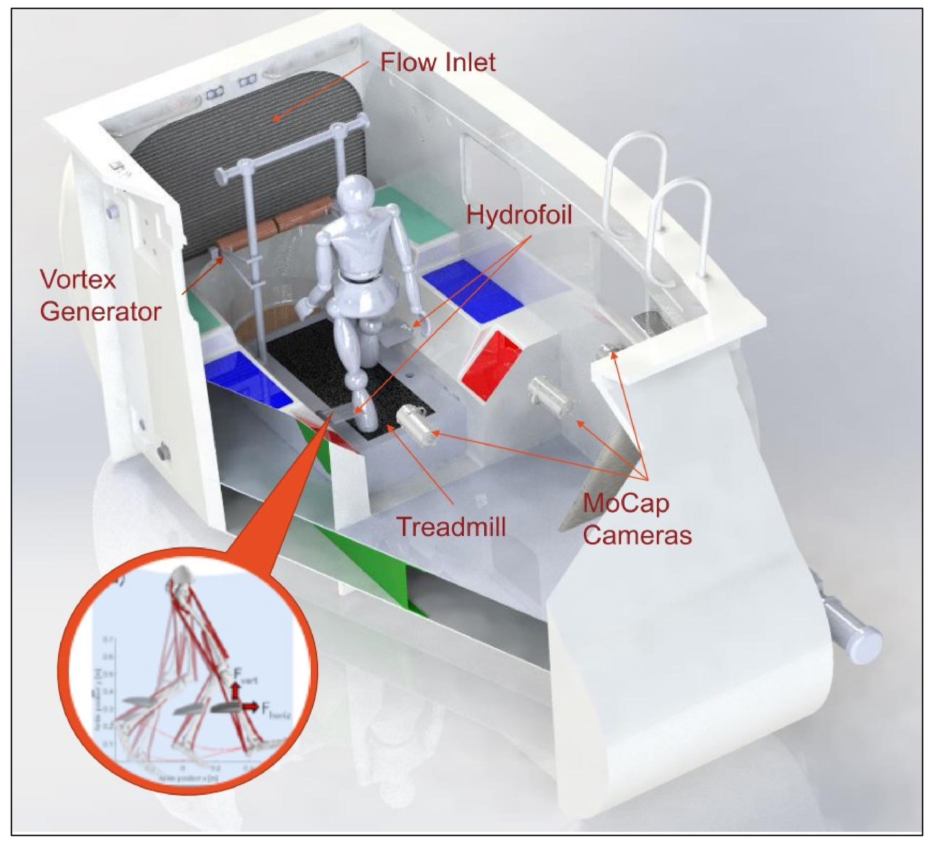
umass.edu/robotics/mrrl/research/assisted-underwater-gait

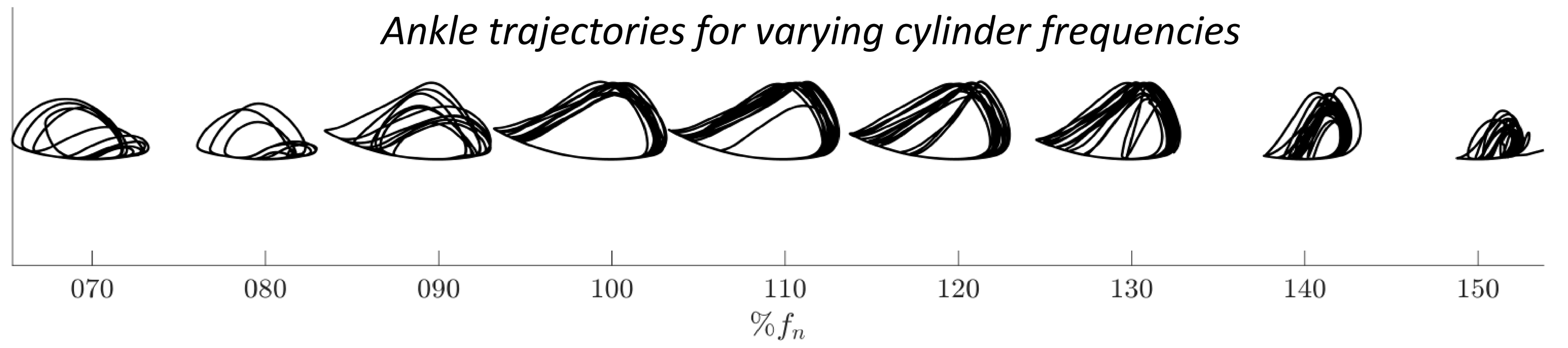


Motivation

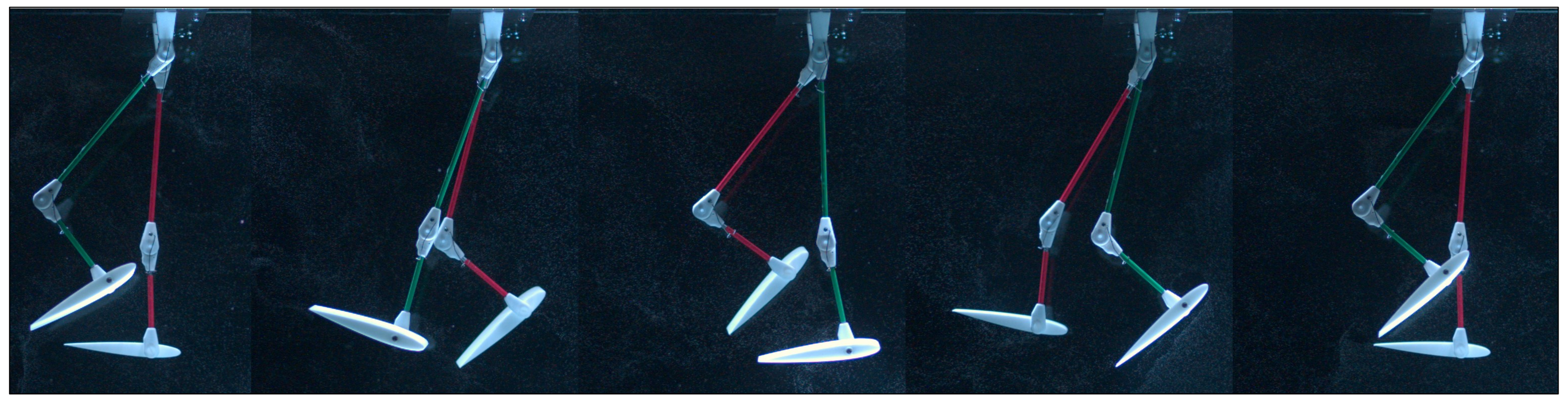
Underwater treadmills are used for gait rehabilitation to leverage the beneficial effects of buoyancy to reduce limb loading. The treadmill operates under a continuous flow of water used to modulate the drag force in the horizontal direction. This project focuses on ways to actively redirect the flow to generate forces on a person's limbs with an attached hydrofoil to assist or resist specific movements as a robotic exoskeleton would do. A wearable hydrofoil underwater system is naturally compliant and can be less bulky than a full exoskeleton. We leverage the effect of the fluid-structure interaction between vortices generated at a controlled speed and frequency and a hydrofoil placed downstream to create underwater human gait trajectories.

Small-Scale Experiments

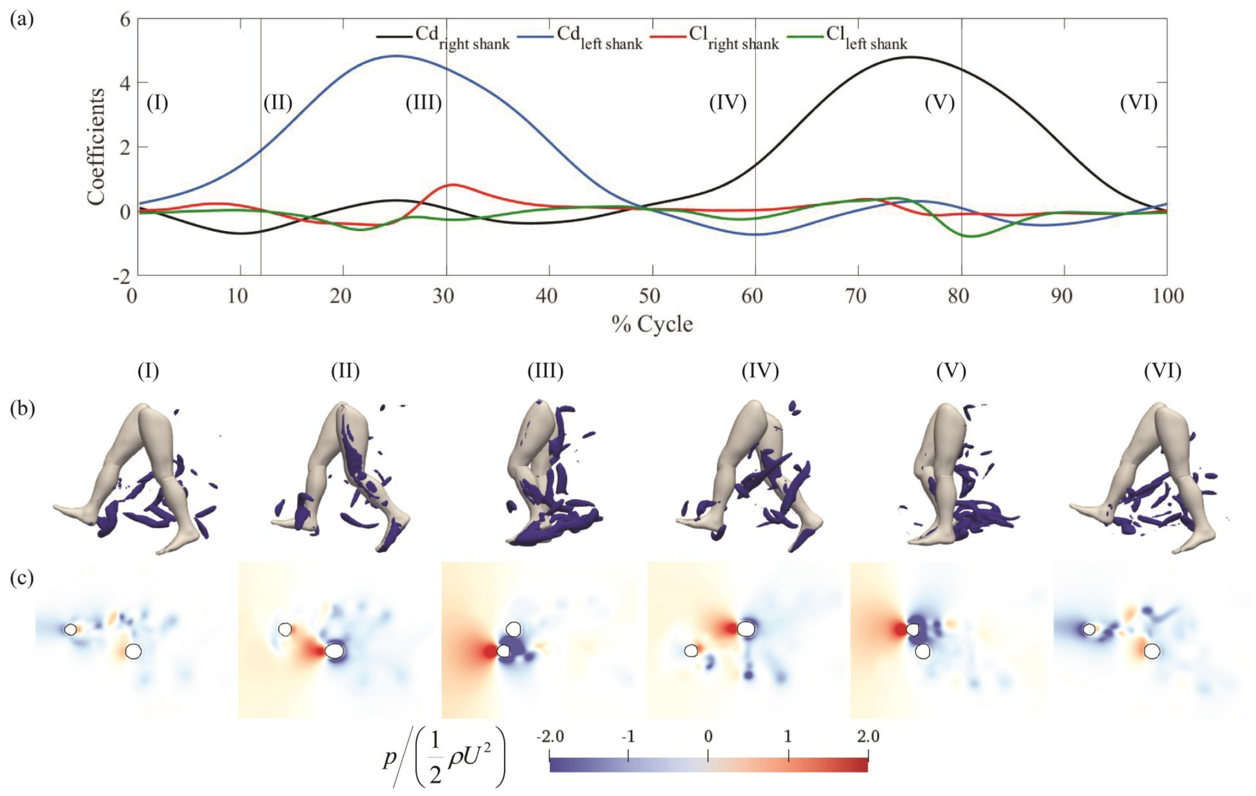
Small-scale experiments allow for rapid parametric studies to determine the effect of varying cylinder rotation frequency and speed and flow rate on the ankle trajectory. Example trajectories for varying cylinder frequencies are shown at right, demonstrating that a proper gait can be maintained for frequencies between 5% lower and 15% higher than the natural gait frequency.



At the small scale, we were able to confirm that the wakes of counter-rotating adjacent cylinders remain independent enough to induce 180° out of phase gait cycles in paired passive double pendulums with end-mounted hydrofoils. A series of snapshots from one of these experiments is shown on the left.

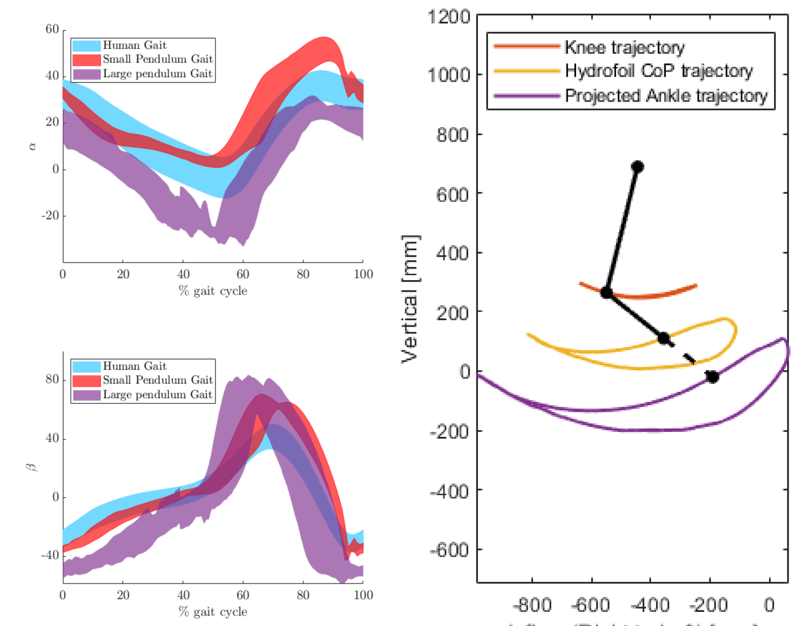


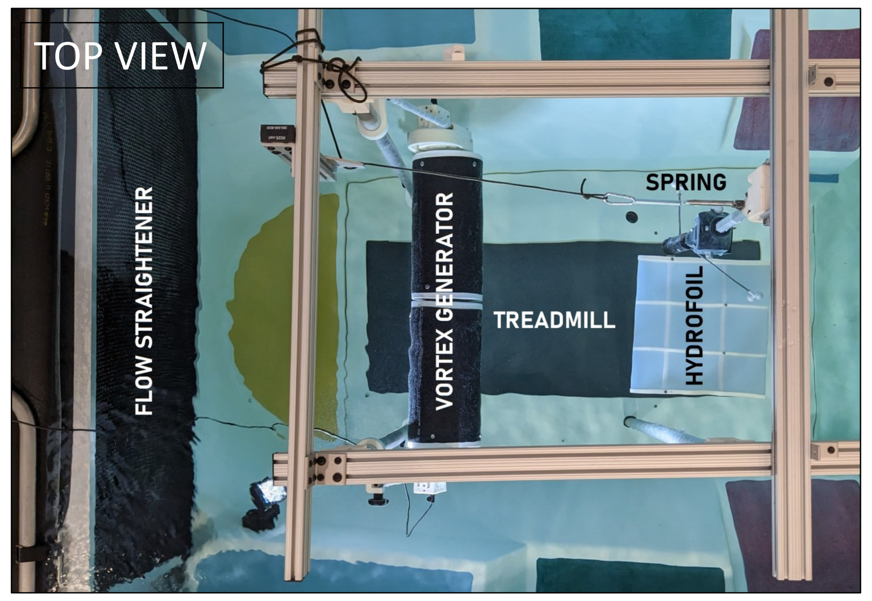
Computational Fluid Dynamics (CFD)

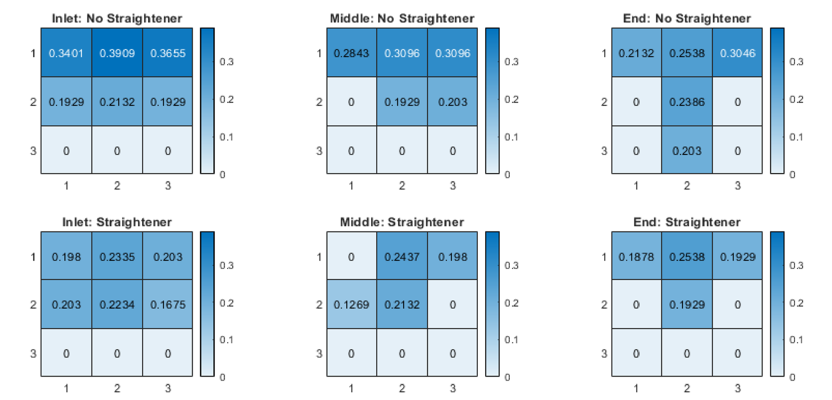


The hydrodynamics forces acting on the legs during walking are investigated using CFD simulations using the Immersed Boundary Method at *Re* = 1500. The drag coefficient on the right shank peaks when the leg is in the middle of the swing phase (at 75% of the gait cycle). The lift coefficient on the right shank peaks when the leg approaches the mid-stance position and is just crossed by the neighboring leg in the swing phase (at 31% of the gait cycle). The peak in the lift coefficient is caused by the large pressure gradient created during the swing phase of the neighboring leg. The lift coefficient remains zero during the entire gait cycle when the simulation is run only for one leg due to the preserved flow symmetry in the crossflow direction around the leg. A horseshoe-shaped vortex ring is generated in the wake during the swing phase (at 80 % of the gait cycle) from both sides of the shank. However, when there are two legs, the vortex ring in the proximity of the neighboring leg does not form due to the disturbances caused by the adjacent leg.

Human-Scale Experiments





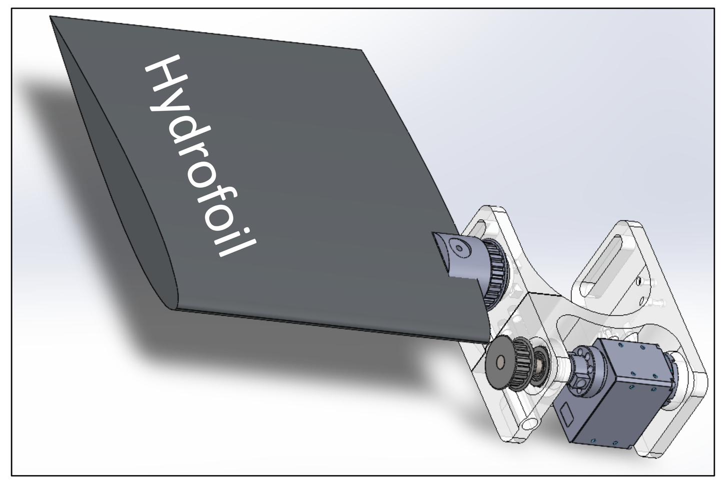


Velocity profiles at different points along the treadmill (m/s)

Human-scale experiments were performed in the underwater treadmill facility in the athletics facility at UMass Amherst. The objective was to recreate the results obtained in the small-scale setup. The major challenges were accommodating the loss of flow quality in moving from a controlled water tunnel to a commercial underwater treadmill. To that end, a flow straightener was designed to make the flow more uniform. Flow measurements indicate that the straightener made the flow from the outlet more uniform but that the flow closer to the wall was much more restricted. To pull the hydrofoil back against the flow, a pre-tensioned spring was connected to the upper segment of the double pendulum. The treadmill would perform this function when the system is transferred to the human. The hydrofoil used in these experiments was 12" x 12", which is larger than those planned to be used in human experiments but is still representative of the motion. The test results indicate that once a repeatable cycle can be achieved, the motion of the human-scale double pendulum closely follows that of the small-scale setup and is similar to human gait kinematics of the thigh, α, and the shank, β.

Wearable Hydrofoil Design

The hydrofoil can be worn on a person's lower leg via a 3D printed mount that uses a timing belt system and a servo motor to actively control the angle of attack of the hydrofoil. This increases the parameter space available to optimize the performance of the system. The assembly is connected to an ankle support attachment that helps distribute the weight while retaining freedom of movement at the ankle. Integrating an IMU into the mount's design provides data about the subject's motion and allow closed loop control of the hydrofoil in response to changes in the user's posture.



Rear view of double pendulum in flow

Future Work and Broader Impacts

Future Work:

•Test the effects of replacing the double pendulum with a human and recreate the experiments
•Test the advantages of the variable angle of attack hydrofoil
•Develop and test closed-loop control systems to modify the kinematics of the system
•Measure the forces generated by the system to develop a dynamic model of the system

Broader Impacts:

- Enable a new type of manipulation strategy, which does not involve direct contact or coupling with the object being manipulated
- Basis for a novel method of natural gait training for persons recovering from stroke or injury
- Extensions to manufacturing and underwater robotics for fluid-based non-contact material handling and manipulation
- Connecting with K-12 students through outreach activities to demonstrate the physics as well as the beauty of engineering systems

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