Flexible Exoskeletons

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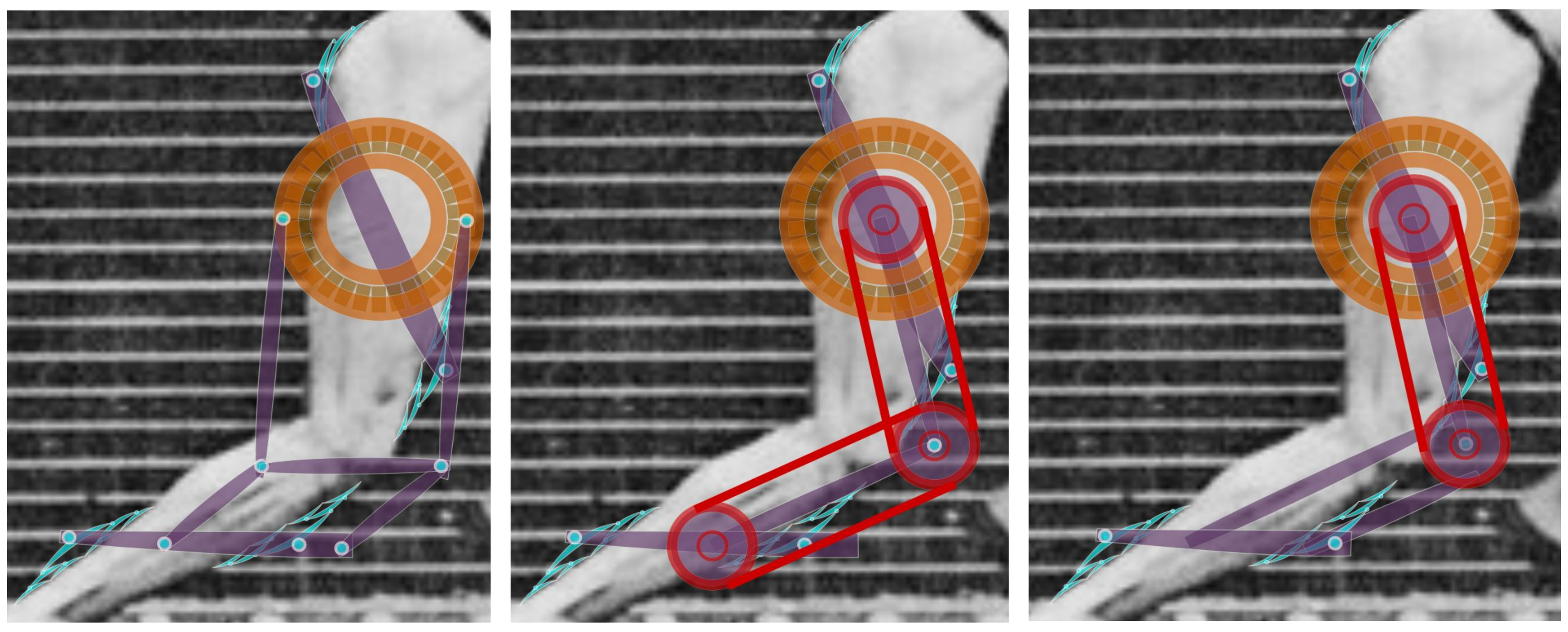
Better Connection, Less Structure

Exoskeletons are devices designed to assist a human operator by amplifying their strength. However, their benefit to the operator depends heavily on the amount by which they can increase to power to weight ratio once the operator dons the exoskeleton. With today's technology toolkit of electric motors, aluminum structures, ball bearing joints, and 3D printed plastic cuffs, this power to weight ratio can increase very slightly or not at all. In this poster I introduce some mechanical design ideas that exploit the potential of flexible robots to address this problem. The ideas I propose here attempt to remove structure from the joints, increase the load-bearing potential of the joint cuffs, and allow a sliding scale of transmitting forces through the human's existing joint structure or through the exoskeleton.

Zero Joint Structure

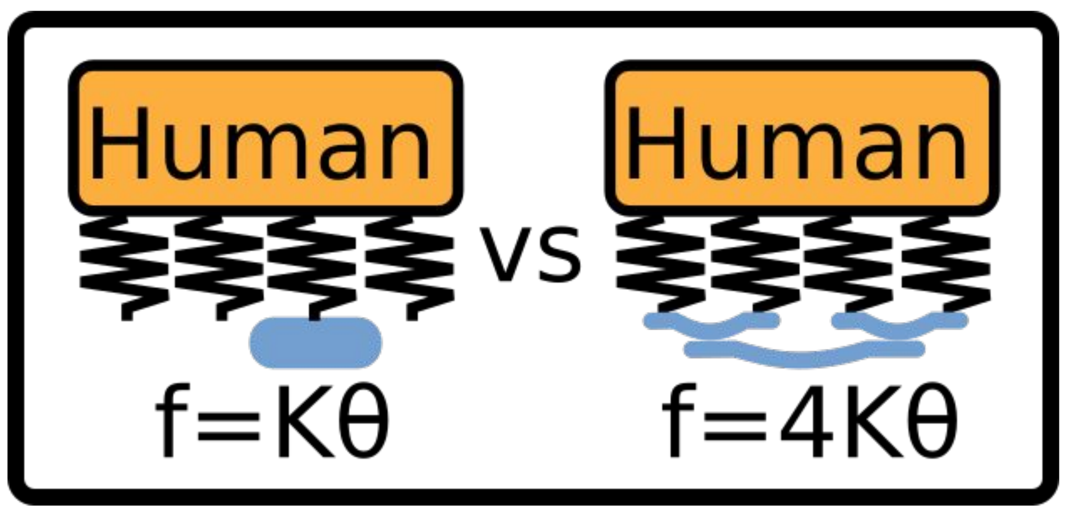


These three transmission designs have the ability to conform to the human's joint axis, and they actuate only the relative rotation of the segments on the shank and thigh. These designs do not need to be located very accurately on the legs in order to properly transmit torques. If the exoskeleton is primarily helping the human resist their own gravity forces, this may even reduce knee compression due to the human's own tendon transmission.

Smooth Transition: Structure — Bypass

The three pictured transmissions incorporate some joints which only rotate slightly as the human leg moves. Transitioning these joints from pins to soft hinge flexures and then to increasingly rigid flexures also transitions the exoskeleton itself from a joint-bypassing to a joint-reinforcing exoskeleton. In the extreme case of strength amplification, where the exoskeleton can lift loads far heavier than a human's joints can bear, the joint-reinforcement is key. In this case the exoskeleton must transmit loads to ground by an indepent load path. On the other hand, when the exoskeleton has capabilities that are on par or slightly weaker than a human, it really just offloads torque generation responsibility from the human muscles. In this case, the bypass behavior is very helpful, because it avoids the problem of alignment and allows the exoskeleton to be far lighter.

Distributing Load with Flexures

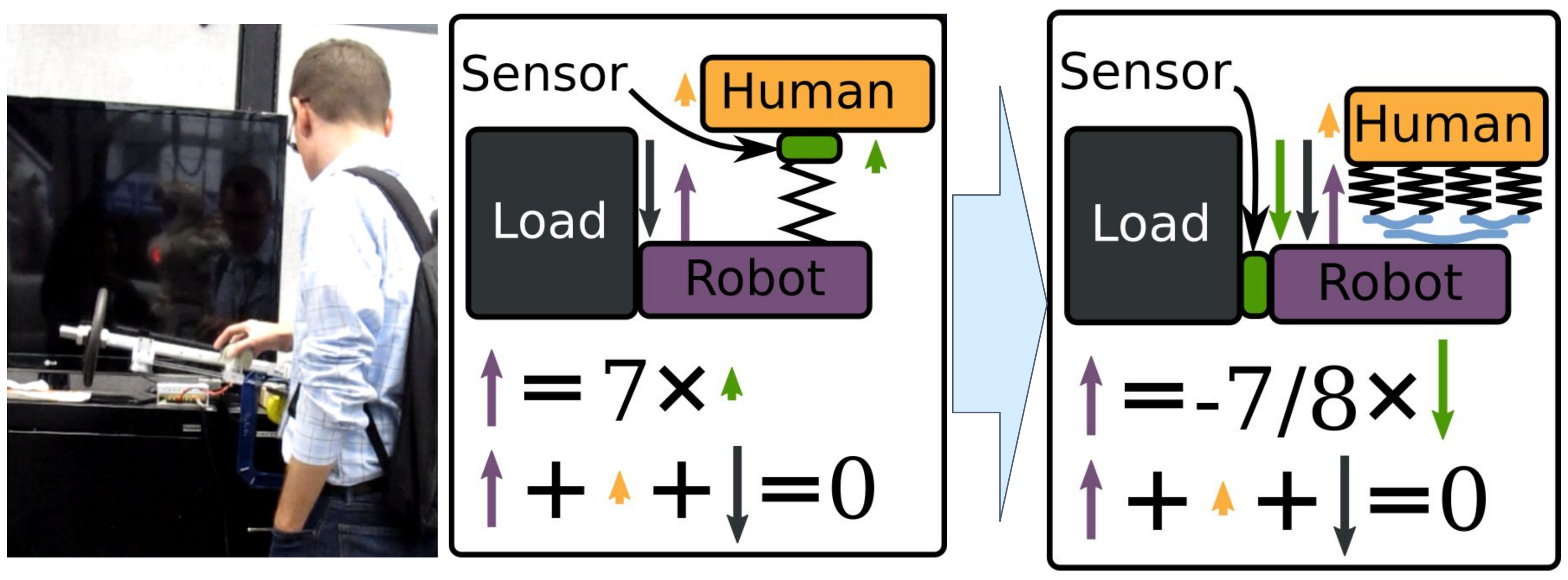


Distributing load evenly over a large area with a stiff-soft windshield wiper flexure could increase the interface stiffness.

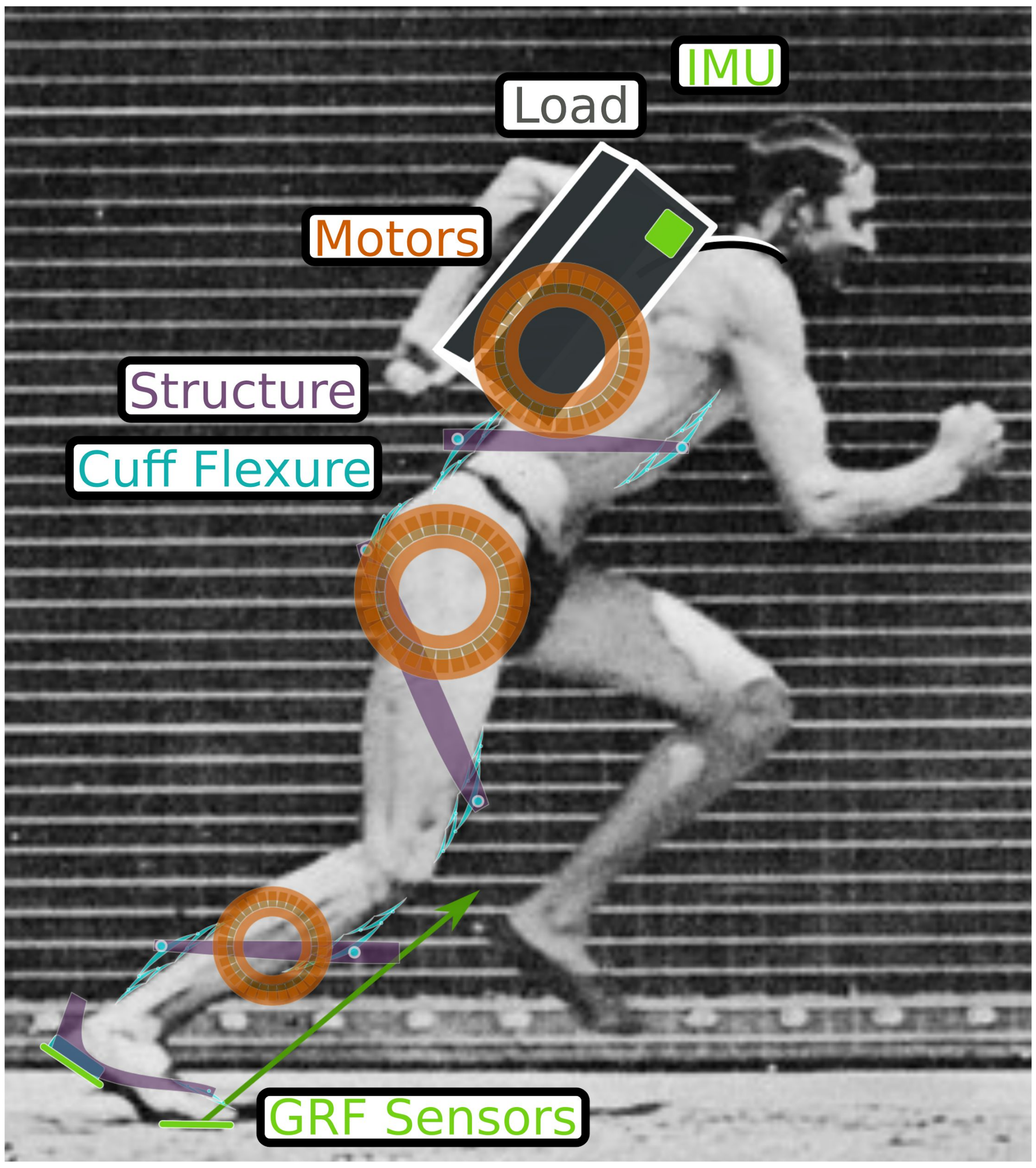
Why use flexures here instead of pin joints? Flexures scale better to high complexity mechanisms due to ease of manufacturing. Shape deposition manufacturing, in particular, could make these flexures by casting rubbery urethane over carbon fiber "wiper blades", essentially just to hold them in place. When the wipers are not in compression, they are a very high degree of freedom mechanism, and having a small restoring spring is convenient.

Strength Amplification Control

- Sensing HRI forces vs. sensing load — same thing.
- Ensure the two compliance ports are passive* (*phase relaxed passivity)
- Amplification is the ratio of the two port compliances



Whole Body Layout Concept



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Pictured: Me wearing the P5 Apptronik Sagittarius Exoskeleton. This exoskeleton is capable of lifting 200 Newtons and walking at 1.0 m/s (not at the same time). It serves as a good example of redundant parallel joint structure. This is an exoskeleton ambitiously designed to help operators lift heavy payloads that could harm their joints, but it is sadly not strong enough to lift such payloads.

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