Shifting the paradigm: An enhanced man-machine interface

Dr. Massimo Sartori is a Professor at the Department of Biomechanical Engineering in the faculty of Engineering Technology at the University of Twente. He is the head of the ERC Project INTERACT which aims to close the knowledge gap between the interaction of the nervous and musculoskeletal systems and promote the development of new human-machine interfaces.

Millions of people are affected by debilitating neurological injuries such as stroke or spinal cord injuries. Recovery from these conditions is a challenging and often, suboptimal process. Dr. Massimo Sartori and his lab are working on improving neurorehabilitation by merging digital multi-scale models of the neuromuscular system with electrical stimulation of the spinal cord and wearable robotic exoskeletons. They are working on two major pillars: fundamental science and applied science. At the core of the first pillar is understanding the neuromechanics of movement which means understanding how the nervous system controls the muscular system to generate movement. "We apply advanced techniques for measuring information from the body. We measure bioelectrical signals and create what we call digital twins or digital copies of a person consisting of digital copies of neurons in the spinal cord and digital copies of muscles. Everything we learn from these digital twins we use it for developing what we call human-robot interface." explains Dr. Sartori. The second pillar, applied science, refers to connecting the human body with assistive robots-wearable technologies that aim to improve the way the body moves after a brain injury such as a stroke. "We try to interface wearable robots with the nervous system of stroke patients so that the exoskeleton can effectively become a natural extension of the body. As soon as the patient doesn't have enough strength to make a specific movement, the exoskeleton can activate itself and help the patient to complete the movement," says Dr. Sartori.

The project INTERACT is essentially about these two goals. First, the researchers aim to build detailed digital twins of stroke patients and understand how muscles, bones, and neurons in the spinal cord interact with each other. Second, they plan to use these digital twins to understand how exoskeletons and neurostimulators such as spinal cord stimulation techniques contribute to altering the functions of neurons and muscles.

The researchers are using a technique called high-density electromyography which records electrical signals from muscle fibers that are directly innervated by alpha-motor neurons in the spinal cord's ventral horn. As alpha-motor neurons branch out from the spinal cord, they physically connect to skeletal muscle. Therefore, there is a one-to-one relationship between the activity in the neurons and the muscle fiber. This synaptic connection makes it possible to use the information gained via high-density electromyography to decode the firing of alpha motor neurons. "The next question is how does this neural activity affect the activity of the musculoskeletal system? The next step is to build muscle models and feed them this neural information, which in turn will simulate how these muscles would generate force. If we have models of all the muscle then we can estimate the force that makes a specific joint move. This force can be measured externally, and it is a way of validating our method. " explains Dr. Sartori. These muscle models can be used to restore neural excitability and estimate the degree of muscle paresis as a consequence of neurological injury. "We use spinal cord electrical stimulation to fine-tune the stimulation parameters until our model tells us that the excitability has been restored and the movement is smooth. We use our models as a magnifier to look and understand what the stimulation is doing to the body. By estimating how much force the muscle can produce we also know how much force the exoskeleton should give to make a full movement. This compensates for the lack of force in a very precise way, because for the first time, we now have a direct estimate of how much force these patients can generate." explains Dr. Sartori.

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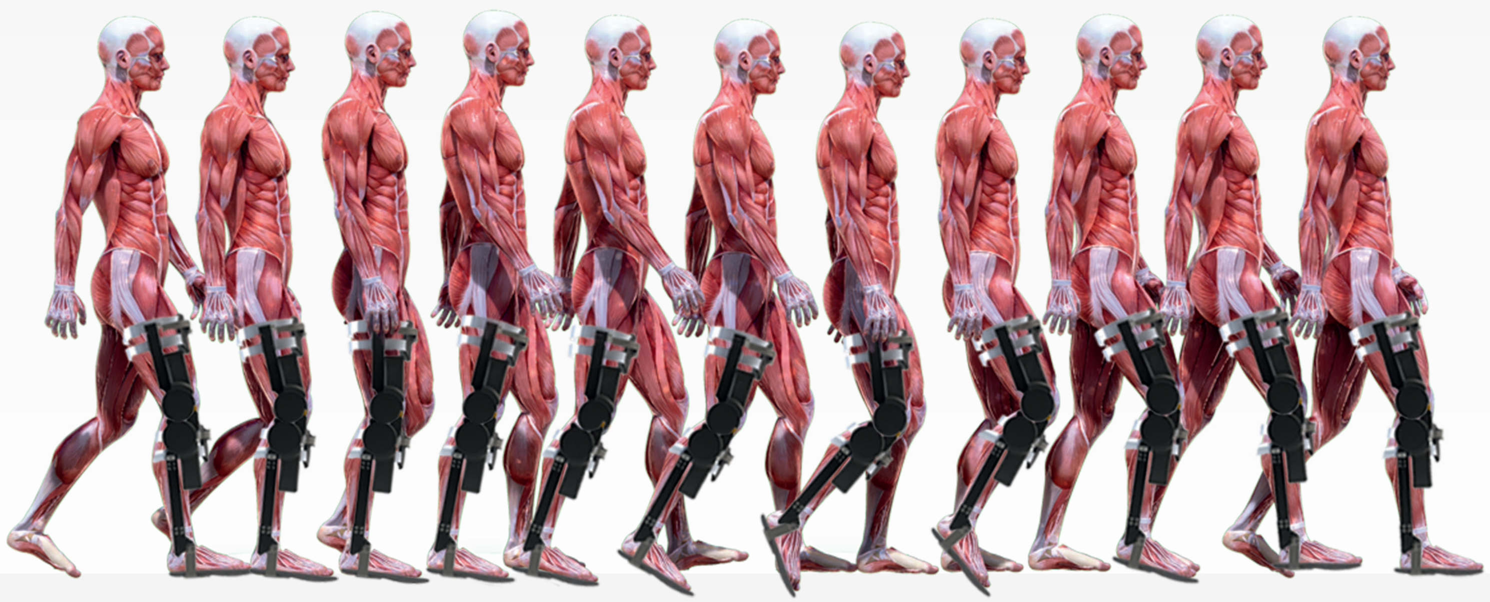
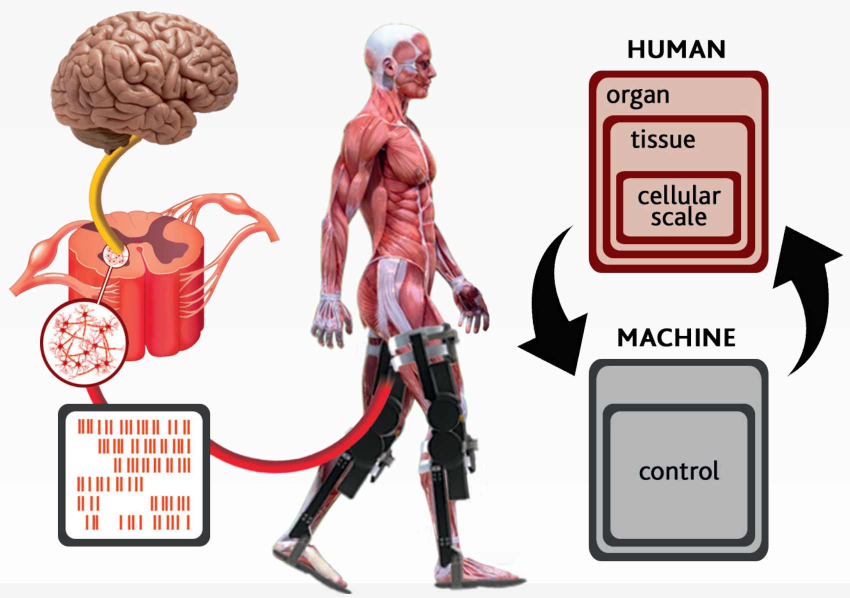
The researchers hope that by assisting the patient as needed they will regain control of their own body and induce positive neuroplastic changes that might lead to improved recovery. "The problem with current rehabilitation robotics is that the patients are passive, so it is the robot that is driving the patient. We want to get rid of these paradigms, and we want to go into a paradigm where the patient is in charge and the exoskeleton only provides the assistance needed to execute a specific task. Otherwise, you will not have positive neuroplastic changes in the neuromuscular system." concludes Dr. Sartori.

What has been achieved so far? The researchers have managed to create digital copies of alpha motor neurons of healthy subjects, and to prove that these digital copies fire just like their biological counterpart. They also developed digital copies of skeletal muscle for which they can estimate the force that the muscle generates and its stiffness. Third, they managed to develop real-time digital twins that operate in real-time and by connecting them to stroke patients they showed that they can be used to control an exoskeleton. The patients managed to regain control of their knees and ankles from a seated position with the support of the exoskeleton. Lastly, they managed to have the exoskeleton support locomotion in healthy subjects. Lastly, the team proved the possibility of interfacing with alpha motor neurons in spinal cord injury patients receiving transpinal electrical stimulation. Results showed the neural interface was sensitive enough to capture subtle neuronal changes induced by the administered spinal stimulation, thereby opening the avenue to the development of closed-loop neuro-modulation technologies.

Dr. Sartori believes that the implications of this project are numerous. The technologies that are being developed can be used to improve neuroprosthesis, robotic prostheses, and bionic limbs, they can be used to preserve the integrity of tissue, and to keep tissues healthy as we age. They can shed the light on how the nervous system controls the musculoskeletal system in healthy subjects, as well as how this communication gets disrupted. Anything that affects movement can be addressed by the knowledge generated by this project whether it's spinal cord injury, Parkinson's disease, cerebral palsy, stroke, multiple sclerosis, or congenital conditions such as Duchenne type of muscular dystrophy. "Through these models, we are extracting a lot of information from the body. We are extracting cellular information from the body and the moment that you have information, then you can carry out predictions. You can use data science and artificial intelligence to predict and diagnose the likelihood of injury or likelihood of recovery. So, you can really start and think about biomarkers of recovery and biomarkers of injury." concludes Dr. Sartori.





INTERACT

Modelling the neuromusculoskeletal system across spatiotemporal scales for a new paradigm of human-machine motor interaction

Project Objectives

The EU-funded ERC project INTERACT creates multi-scale models of human–machine interaction for novel closed-loop control paradigms. INTERACT uses recording and numerical modelling to decode the cellular activity of motor neurons in the spinal cord at a high resolution, aiming to demonstrate how motor dysfunction is repaired by inducing changes in neuromuscular targets. Learning to control the stimuli that govern neuromuscular function will enable machines to co-adapt with the human body and will promote the development of man–machine interfaces from neuroprostheses to robotic limbs and exosuits.

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Massimo Sartori is Professor and Chair of Neuromechanical Engineering at the University of Twente (Faculty of Engineering Technology, Department of Biomechanical Engineering) where he directs the Neuromechanical Modelling & Engineering Lab. His research focuses on understanding the interplay between the nervous system and the musculoskeletal system, both in healthy and impaired individuals for the development of human-robot interfaces for restoring movement.

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