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

Sprawozdania

Informacje na temat projektu

INTERACT

Identyfikator umowy o grant: 803035

Strona internetowa projektu

DOI
10.3030/803035

Projekt został zamknięty

Data podpisania przez KE
12 Grudnia 2018

Data rozpoczęcia
1 Stycznia 2019

Data zakończenia
30 Czerwca 2024

Finansowanie w ramach
EXCELLENT SCIENCE - European Research Council (ERC)

Koszt całkowity
€ 1 500 000,00

Wkład UE
€ 1 500 000,00

Koordynowany przez
UNIVERSITEIT TWENTE
Netherlands

Periodic Reporting for period 4 - INTERACT (Modelling the neuromusculoskeletal system across spatiotemporal scales for a new paradigm of human-machine motor interaction)

Okres sprawozdawczy: 2023-07-01 do 2024-06-30

Podsumowanie kontekstu i ogólnych celów projektu

Robotic exoskeletons and neuromodulation devices have long been designed with the goal of enhancing or restoring human movement. However, despite advances in surgical procedures, biocompatible implants, and mechatronics, current solutions have had only modest results in healthy and neurologically impaired individuals. A central element hampering progress is the difficulty of predicting how the human body responds and adapts to neuro-robotic interventions in space (e.g. from cellular to organ scales) and in time (e.g. from milliseconds to months or years).

Neuro-robotic technologies expose biological targets in the neuromuscular system (e.g. neurons, muscle fibers) to electrical and mechanical stimuli. For instance, prolonged mechanical strain and loads to skeletal muscles may lead to changes in fascicle length, strength or volume. Similarly, electrical currents to the spine may alter neuronal excitability. Whether or not these changes improve the way a patient moves in the long term cannot be predicted before-hand. If we could predict how a person’s neuromuscular system responds and adapts to neuro-robotic interventions and steer such adaptation over time to induce a movement benefit, then a new era in closed-loop rehabilitation robotics would begin.

This represents a major challenge, which if addressed, would lead to a paradigm shift in neurorehabilitation technologies, with profound repercussions in broad scientific domains spanning from movement neuromechanics to robotics. Addressing this challenge would also have tremendous socio-economic impact, e.g. neurological injuries such as spinal cord injury or stroke leave every year 5 million people disabled worldwide. For these individuals, recovery is often suboptimal leading to permanent impairment in increasingly large portions of the population.

INTERACT will create radically new digital models of the human neuromuscular system that can predict how the human body adapts over time with levels of precision not achieved before. This represents a new class of digital human twins (e.g. a digital copy of a person’s neuromuscular system) that can develop themselves or age over time in concert with their human counterpart. These models will be used to establish radically new closed-loop control paradigms. This will lead to a new class of neuro-robotic technologies that interact and co-adapt with the body based on feedback from the neuromuscular system, thereby ‘closing-the-loop’ with human biology.

Prace wykonane od początku projektu do końca okresu sprawozdawczego oraz najważniejsze dotychczasowe rezultaty

The INTERACT team established novel methodologies for creating digital copies of a person’s neuromuscular system. The first part of the project focused on modelling the behavior of a type of neural cells located in the spinal cord that are responsible for the generation of movement, i.e. the α-motor neurons. The team described how α-motor neurons generate the electrical activity controlling the activation of skeletal muscles.

NEURONAL MODELLING:
The functional structures of the α-motor neurons (i.e. soma, dendrites) were modelled as biophysical compartments capturing the anatomy and function of the neuron (e.g. soma size, channel dynamics, etc.). A major challenge was the identification of such properties from large sets of α- motor neurons in human subjects and in a non-invasive way (i.e. these studies are typically done in animal preparations using invasive techniques). To address this challenge, the team developed new non-invasive and clinically-viable system identification methods to decode the activity of α-motor neurons from multiple high-density electromyography recordings. Together with advanced techniques for signal processing, this technology allowed the identification of individual α-motor neurons during isometric and dynamic tasks such as walking. This new approach allowed creating digital versions of a person's α-motor neurons (e.g. in silico neuronal copies) that behaved similarly to their biological "counterparts".

The process involved two major steps. First, the calibration of in silico neuron's parameters for reproducing the firing behavior of the experimentally-decoded α-motor neuron. Secondly, the creation of a person-specific representation of the entire α-motor neuron pool based on statistical distributions of the calibrated model parameters. These results are now leading to new concepts of human-machine interfacing that enables continuous neural of robotic of robotic leg exoskeletons and bionic legs by individuals with neuromuscular impairment.

SKELETAL MUSCLE MODELLING:
The INTERACT team also created digital copies of skeletal muscles. A new model was proposed for the estimation of musculoskeletal stiffness during dynamic movements, with a focus on the human leg. State of the art approaches largely rely on biological joint perturbation techniques, which alter musculoskeletal function and prevent measuring stiffness in natural (unperturbed) conditions. INTERACT created a new approach that is not based on joint-perturbation, but rather decodes stiffness from muscle electromyography recordings and leg kinematic data. This methodology, was recently validated against robotic joint perturbations and ultrasonography, providing direct evidence that the INTERACT approach decodes accurate stiffness estimates at multiple anatomical scales including: joint, single muscle and single tendon level for the ankle musculoskeletal complex. This is now opening to new views into how spinal neurons controls muscle impedance and resulting body motions in natural conditions with large implications for neurorehabilitation and robotic control.

Moreover, the INTERACT team employed an innovative in vitro approach to study how skeletal muscles alter their biological structure when exposed to mechanical stimuli over large periods of time i.e. four weeks. We grew muscle tissues on a chip starting from a gel-cell mix containing human induced pluripotent stem cells. We locally tuned the mechanical and chemical environment, with high precision, to influence muscle tissue formation and adaptation to mechanical stimuli across 30 days. Results showed this in vitro approach allows observing muscle adaptation with high levels of precision not attainable in vivo, laying the basis for self-adaptive muscle models.

NEURAL CONTROL OF WEARABLE ROBOTS:
The INTERACT neuro-muscular modelling technology was employed for the control of wearable robotic exoskeletons. The team conducted a series of studies that proved a crucial concept, i.e. whether neurologically injured patients could regain control of their paretic legs using exoskeletons

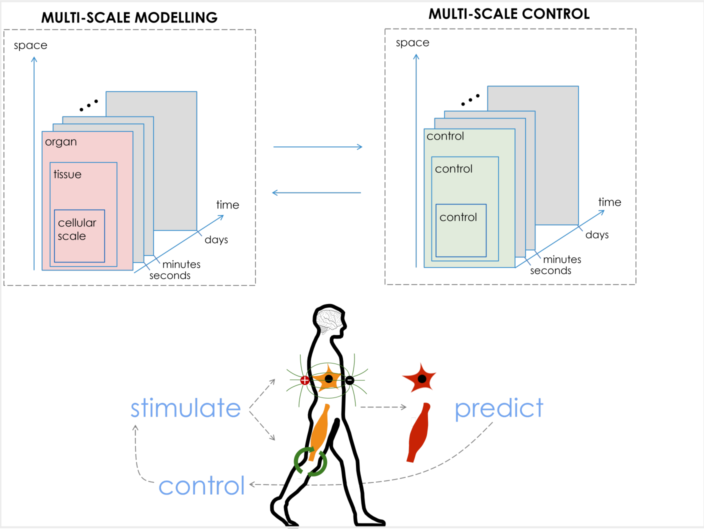
controlled via the patient's digital twin. Key results showed it was possible to create digital twins for both spinal cord injury and post-stroke individuals. Digital twins were used to establish a new patient-exoskeleton interface, which enabled patients to gain volitional control of exoskeletons and move again their paretic legs in ways that were not otherwise possible. More recently, the INTERACT technology has been successfully demonstrated for the continuous neural control of bionic legs, during repertoire of locomotion tasks, in individuals with transtibials with transtibial amputation.

Innowacyjność oraz oczekiwany potencjalny wpływ (w tym dotychczasowe znaczenie społeczno-gospodarcze i szersze implikacje społeczne projektu)

Current neuro-robotic technologies do not interact directly with biological tissues in the neuromuscular system. That is, they do not consider how biological targets (e.g. joints, tendons, muscles, nerves) react and adapt to robot-induced mechanical or electrical stimuli. This is a major element hampering progress in human-robot interaction for movement enhancement or restoration.

INTERACT proposes a complete re-examination of how neuro-robotic technologies are controlled for optimal interaction with the human body. The project proposes a new theoretical, computational and experimental framework for "closing-the-loop" between wearable technology and human biology, thereby shifting the paradigm in current neuro-robotic control theories. Through this framework INTERACT will lead to a new class of neuro-robotic systems that will deliver coordinated electro-mechanical stimuli to alter, in a controlled way, neuromuscular form and function in space (e.g. from cellular to organ scales) and time i.e. time scales ranging from seconds (e.g. a movement cycle) to months (e.g. recovery stage following neuromuscular injuries) and beyond (e.g. across ageing stages).

The impact that this will have on human health is enormous. INTERACT will open new avenues for preserving human tissue integrity throughout highly dynamic tasks or throughout ageing. It will enable detecting disruptive neuro-muscular alterations ahead of time and correcting for them, thus preventing for the onset of future injury or degenerative disorders, i.e. osteoarthritis. It will enable tuning the human for optimal motor performance or triggering regenerative processes to repair compromised movements. Through this project, the INTERACT team will open a new research line in movement neuro-mechanics on systems with interacting biological and artificial components, with broad implications for neural-engineering and robotics. This will disrupt human-robot interaction technologies at a fundamental level in any of its applicative domains: from neuromodulation to neuroprosthetics, from robotic limbs to mechatronic exoskeletons and exosuits.



sartori-interact-pr1.png

Ostatnia aktualizacja: 17 Lutego 2025

Permalink: https://cordis.europa.eu/project/id/803035/reporting/pl