SOCKET SENSE
A tailored fit of the future
Horizon 2020 Project No.: 825429
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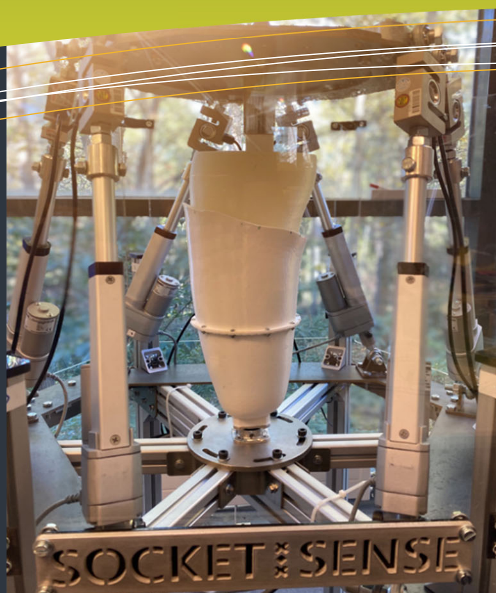

A Novel Mechatronics-Twin Framework based on Stewart Platform

Within the project SocketSense (EU H2020), a novel mechatronics-twin framework has been developed. This framework integrates advanced biomechanical modeling and simulation capabilities with the support for physical testing by a Stewart Platform for effective exploration of operational behaviors of prosthetic sockets with amputees.

Limb amputations cause serious physical disabilities that compromise the quality of life of many people around the globe. Limb prostheses offer a solution to reduce the negative impact of such disabilities, attempting to restore a normal functionality and amputee autonomy, as much as possible. As a critical interface between the amputee (natural) stump and the prosthetic (artificial) device, a suitable prosthetic socket must ensure efficient fitting, appropriate load transmission, stability, and control. The performance often constitutes a key factor for the success or failure of the prosthesis itself. The optimization of prosthetic sockets is however a difficult task as each solution is inherently individual, while from the fact that a wide range of operational conditions can only be partially observable or quantifiable.

This mechatronics-twin framework addresses this challenge by serving as an analytical replica for revealing the complex operational interplay of amputee, prosthetic device and prosthetic socket. By the overall concept, it is similar to the notion of *digital-twin* in regard to the replication of a physical target system on the basis of measurements. The approach addresses however in particular the challenge of complex biomechanical dynamics of prosthesis operation as well as the need of physical replica for data generation and sensor calibration. A six-degree-of-freedom parallel manipulator referred to as SP (Stewart Platform) has been adopted for a refinement of the digital virtual replication given by modeling and simulation. Clearly, any approaches that rely on repeated experimentation on the amputees will not be preferable. For example, this would in the worst case cause further trauma to the amputees.

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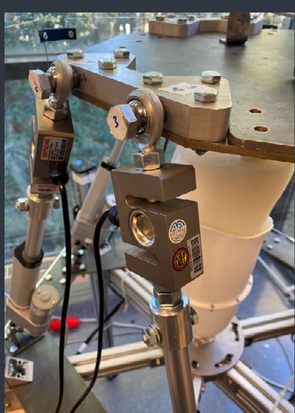
Mechatronics-Twin

A mechatronics-twin is a novel technical solution currently being developed at KTH Royal Institute of Technology, Sweden, to allow both virtual and physical replications of the physical dynamic process of concern.

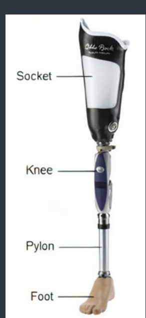


Stewart Platform

A Stewart Platform is a six-degree-of-freedom parallel manipulator widely used as the motion base for flight simulators, antenna positioning systems, machine tool technology, etc.

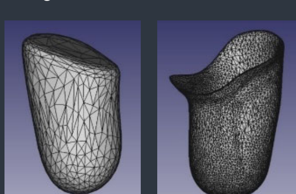
Transfemoral prosthesis

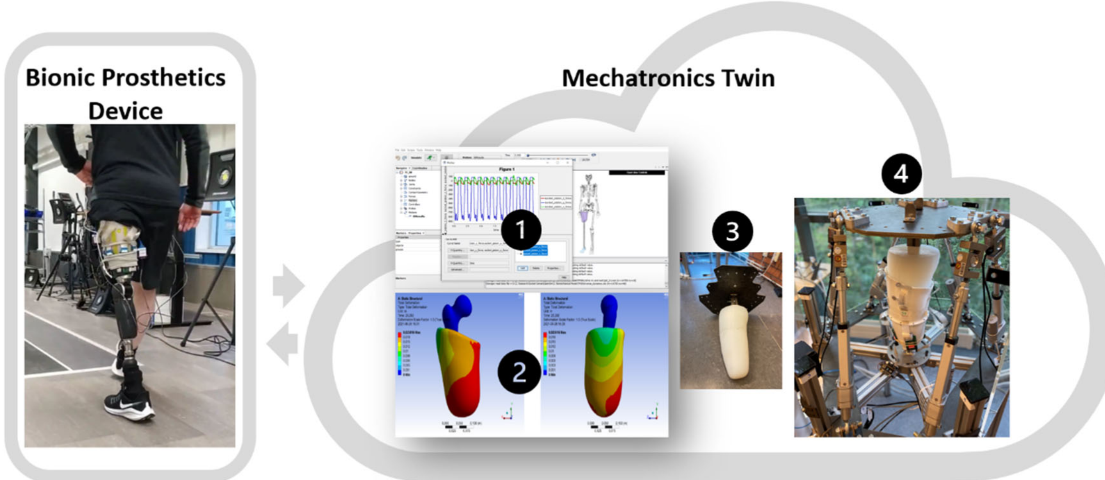
The usage of prosthetic device aims to restore the ambulation and self-esteem of amputee as much as possible. The major components of a transfemoral prosthesis include socket, suspension, knee joint, pylon and feet. Among these components, the socket serves as the interface between the residual limb and the prosthesis. It must protect the residual limb and appropriately transmit the forces associated with standing and ambulation.



3D Printing and Prototyping

The replicas for physical testing are defined with the measurements of target femurs, stump assemblies and sockets, and produced with a combination of 3D printing and shell mold casting.





Overview of the mechatronics-twin that allows both virtual and physical replications of prosthetic device

The mechatronics-twin framework allows both virtual and physical replications of prosthetic device. The virtual re-plication is supported by ❶ Biomechanical modelling and simulation and ❷ FEA (Finite Element Analysis). The physical replication is supported by ❸ 3-D printing and prototyping, and ❹ Physical testing by Stewart platform.

The **Biomechanical modelling and simulation** aims at eliciting the most fundamental operational characteristics of prosthetic device as an integral part of amputee. Within the mechatronics-twin framework, it provides the support for estimating the piston-forces and moments within the amputee stump-socket assembly during walking. Knowledge of such physical interactions is essential for more detailed analysis of stump and prosthesis dynamics. The support is based on OpenSim[1], which is an open source tool for the modeling, simulating and analyzing of neuromusculoskeletal systems.

[1]: https://simtk.org/projects/opensim

The goal of **FEA (Finite Element Analysis)** is to provide an effective characterization of possible intra-socket load conditions of concern before any further physical tests.

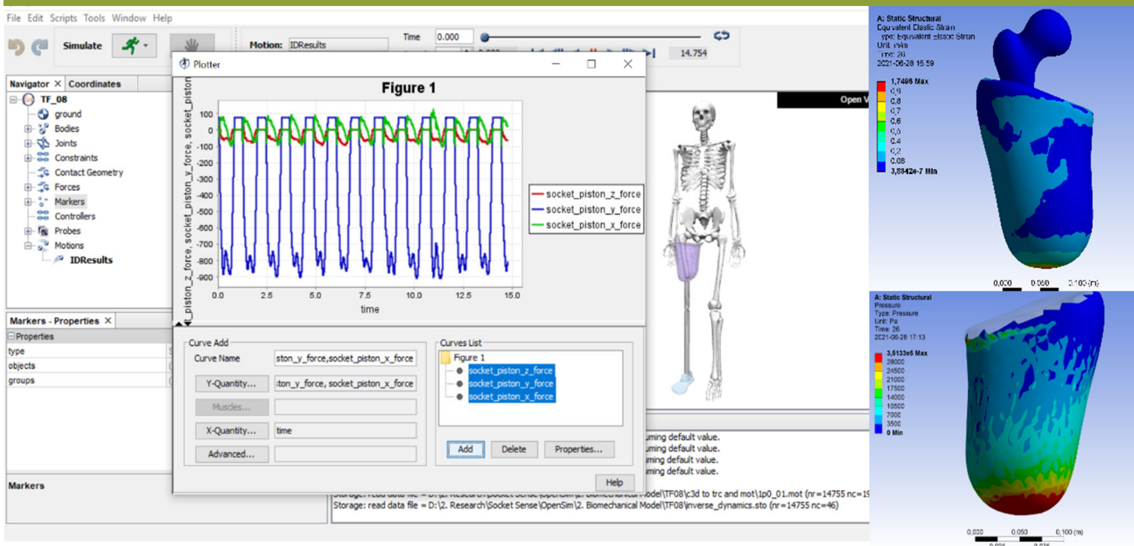
"The mechatronics-twin framework serves as an analytical replica for revealing complex operational interplay of amputee, prosthetic device and prosthetic socket."

Within the mechatronics-twin framework, the FEA step provides the initial support for establishing the virtual behaviors relating to the contact forces on stump surface, based on the internal joint reaction data from the biomechanical modelling and simulation. In addition, the FEA also provides useful insights about contact forces and dis placement on the interface of stump and socket. The analysis is based on ANSYS Workbench[2], which is a commercial software tool providing support for advanced FEA.

[2]: https://www.ansys.com

This **3-D printing and prototyping** is responsible for producing the femur-stump assemblies and sockets. Within the mechatronics-twin framework, it provides the physical replica of femur-stump assemblies and prosthetic sockets for further physical testing by the test-rig. 3D printing is used mainly due to the excellent lead times. The approach also allows a geographical distribution of activities, e.g. having the patient measurement in one region of the world and the testing in anther region. The printing and prototyping of physical replicas use the measurements of related femurs, stump assemblies and sockets. The stump replicas are produced by a shell mold casting process, for which the shell is first created based on the geometry of stump.

Within the mechatronics-twin framework, the **physical testing by Stewart platform** allows a more detailed investigation of operational behaviors of prosthetic devices as an integral part of amputee. The goal is also to refine, verify and validate the corresponding virtual behaviors using the physical prototypes femur-stump as-



A snapshot of biomechanical model and related virtual operation data.

sembly and prosthetic socket. As one key step in the process of motion control, a lumped-parameter model is used to specify the target plant given by femur-stump assembly and socket. This method allows the complex operational behaviors of prosthetic devices to be captured by parameterized spring-mass-damper models. Especially, the joint movement along each DoF (Degree of Freedom). For the motion control of testing, the current framework adopts a cascaded force-force-position control approach. The design consists of PID controllers for position and force regulation, and analysis functions for generating the reference kinematics.

The results by case study show that the proposed solutions can fulfill the expected goals. Additionally, the current design of this framework opens up many perspectives for future research. In further studies, the modeling support can be enhanced with a mixture of heterogeneous friction coefficients as well as more complex hyperelastic material models for the stump. The simulation and testing cases can also be automated for different load or gait conditions. A refinement of the controller design would also improve the control performance. Various software and hardware technologies would also need be explored to support the implantation of the proposed framework in industrial scale.

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SOCKET SENSE

The SocketSense Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under the grant agreement No 825429. The project aims to develop an innovative prosthetic socket system through the integration of advanced sensing, data analysis, AI methods, embedded platforms and cloud computing.

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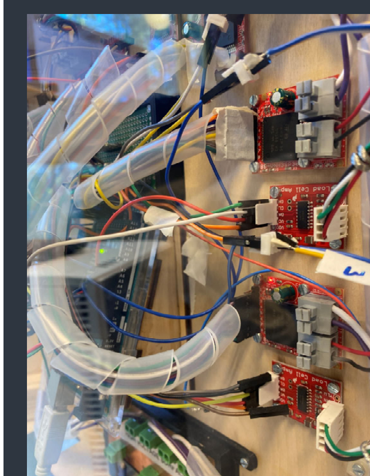
Exploring Opportunities by Virutal and Phyical Simuations with a Cyber-Physical System for Effective Perception of the Operations of Prosthetic Sockets

The mechatronics-twin framework aims to form an important basis for successful deployment of flexible wear-able sensors inside bionic prosthetic sockets for real-time monitoring of dynamic load conditions.



By generating operational data with well defined fidelity, the replicated virtual and physical behaviors allow the training and testing of data-driven algorithms for the sensor functions.