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Titel
Three-dimensional testing of orthopedic devices with a robotic test system

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Zusammenfassung
The purpose of this study comprises the development of a robotic test system to test prosthetic feet with various complexity: Uniaxial loading, two- and three-dimensional. Further, a strategy was developed which translates motion capture data from a subject to the robot as kinetic input.

Hintergrund
Prosthetic feet are available in various designs. Thus, patients and prosthetists are facing the challenge of matching functional demands with the mechanical properties of prosthetic feet.
In order to solve this dilemma, tests of prosthetic feet in specific scenarios (activities of daily living) would be needed to quantify certain characteristics of a prosthetic foot. Reproducing these loading scenarios with human trials is cumbersome and hardly repeatable with acceptable accuracy. Designing or adapting test benches to execute complex trajectories is challenging and time-consuming especially if numerous activities shall be evaluated.
Past studies have taken advantage of six-axis robots to reproduce three-dimensional trajectories for testing but required position adjustments [1, 2] to mimic ground reaction forces (GRF) . This work presents an alternative approach for the control strategy that accommodates differences of prosthetic feet and adapts the robot trajectory to replicate GRF.

Material Methode; Durchführung/ Prozess
A prosthesis is mounted on the robot (KUKA) with a custom fixture and a force plate (AMTI) which is mounted on the floor in front of the robot measures the ground reaction forces during testing (Fig. A). The position control mode would not be sufficient for recreating the desired forces. Therefore, a control system was developed in MATLAB that automatically adapts the robot trajectory based on the force deviation from the target ground reaction force. Over the

course of several iterations, the control adjusts the robots movement until the forces converge towards the target.

The feasibility of the control was first tested for uniaxial loading at different angles in the sagittal plane. The complexity of the trajectory was then further increased by performing a roll-over movement with the specific M-shape of the vertical forces.

Ultimately, a subject's gait pattern that has been previously recorded by a motion capture system (VICON) and the corresponding forces were used as input.

Ergebnisse

The control of the robot has been refined from a position control to a force control that allows performing the aforementioned tests and self-adjust its trajectory. As a result, the force error decreased over the course of several iterations (Fig. B).

For uniaxial loading and roll-over movement, the root-mean-square-error (RSME) decreased after the first iterations and converged to low values over time of testing.

Further, it was possible to transfer the gait data from the motion capture system to the robotic test system to replicate a realistic movement with high reproducibility. The control was able to approximate the ground reaction forces with some remaining deviation (Fig. C).

Diskussion/ Schlussfolgerung; Fazit für die Praxis

The results of this first feasibility test demonstrate that tests for prosthetic feet can be performed ranging from simple, uniaxial loading to roll-over movement and even gait pattern from a subject. The developed control strategy adjusts the robots movement in a correct way so that the deviation from the target force is reduced. Additonal adjustment of the control parameters and its model is needed to further improve the replication of GRF.

The robotic test system has the potential to become a powerful tool for investigating the functional properties of prosthetic feet during everyday activities by performing patient-specific movements with high reproducibility. This allows for the comparison and functional characterisation of prosthetic feet and eventually become a benefit for prosthetists and patients.

Further, the robotic test system offers a wide range for prosthesis testing:

o Testing of different underground

o Addition of prosthetic joints like knee joint to test swing phase and control of active knee joints o Testing of interface forces (Shaft – Stump) in realistic conditions

o Evaluation activities with a high risk of injury

The usage of the robotic test system with the developed force control contribute valuable knowledge during the early development of prosthetic devices and theirs test benches by transferring realistic loading scenarios to a system with high reproducibility.

Literaturreferenzen

[1] Starker, Felix: Simulation of the Prosthetic Gait Using a Six-Axis Industrial Robot Article. In: Orthopädie-Technik 64 (2013), No.9, S.36-45

[2] Ronkainen, J. A.; El-Kati, R. F.; Fleming, P. R.; Forrester, S. E. (2010): Application of an industrial robot in the sports domain: Simulating the ground contact phase of running. In: Proceedings of the IMechE 224 (4), S. 259–269.

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