Comparison of different actuation modes of a biomechanical human arm model in an optimal control framework

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The number of elderly people in all business areas will keep on growing in the next decades due to the ongoing demographic change. Especially in branches where the amount of manual work tasks is still high, like e.g. automotive final assembly, the need for individualized, safe and ergonomic work places, processes and tools raises continuously. The state of the art approach to assess ergonomic aspects in these fields is to work with human workers, which operate on physical prototypes. Such a reactive proceeding is expensive, slow and allows only for minor modifications due to the progressed status of the construction process. Therefore, there is an increasing demand from industry for tools that allow to include models of humans in the simulation process, which enable it to predict human motions and behavior in an early stage of development, so that ergonomic evaluations can already be done when working with digital prototypes.

Modelling and controlling a digital human model (DHM) is a challenging task, and the scope of ergonomic evaluation adds some additional requirements to the generated motions. Even a simple "reaching for an object" task can be fulfilled by a multitude of solutions (trajectories, velocities, accelerations) [1]. When modelling (parts of) the human body as multibody system (MBS), this means that there is an infinite number of possible solutions to get from a given start configuration to a certain end configuration. When controlling a DHM, this kinematical redundancy should be solved in a way, a real human might or at least can do it, to get ergonomically significance. When working with biomechanical musculoskeletal models, the problem of anatomical redundancy comes up additionally. Due to the fact that humans have more actuators (muscles) than kinematical degrees of freedom (DOF), even one and the same motion can be generated by a multitude of muscle actuations.

In [2,3], an appropriate DHM modelling approach with an optimal control (OC) framework for motion generation is presented. Human bones are modelled as rigid bodies and connected via joints, to actuate the model joint torques can be used or simplified hill type muscles can be added to the model. Additionally, we developed an approach which allows us to use *time invariant muscle synergies* as control parameters for our DHM [4]. Muscle synergies are one hypothesis in neuroscience to explain how the human central nervous system (CNS) might simplify motor control, where one synergy stands for a group of muscles that can be activated synchronously in a fixed balance that does not change over time [5].

In our control framework, motions can be generated by three different actuation modes (AM). In AM1, joint torques are used, in AM2 the hill-type muscles are actuated directly and individually, and in AM3 muscle synergies are used as control parameters for the hill-type muscles. Actuation signals are generated in a generic manner by the OC framework only by defining start and end configurations of the MBS. The joint torques (AM1) respectively muscle actuations (AM2 & AM3) which lead to the resulting trajectories, velocities and accelerations that fulfill the defined "goal" are pure outcomes of OC framework, and depend on the minimized OC cost function.

We performed experiments in the motion lab and measured trajectories and electromyography (EMG) data for a multitude of different motions. From the EMG data we extracted *time invariant muscle synergies* which are used in AM3 (see [4]).

In this paper, first simulation results are presented and the simulated motions are compared to those measured in the motion lab in order to validate the results. We investigate the characteristics of human reaching motions that were measured at the *basic reaching test* [4] (Fig. 1 *left*) with the focus on the chosen trajectories (Fig. 1 *middle*) and velocity profiles. We use a 5 DOF human arm MBS model including 29 hill-type muscles (Fig. 1 *right*) to simulate the reaching motions under similar specifications as done in the experimental setup. We then compare the resulting trajectories and velocity profiles with those we have measured in the lab, and examine the influence of the distinct actuation modes (AM1-AM3).

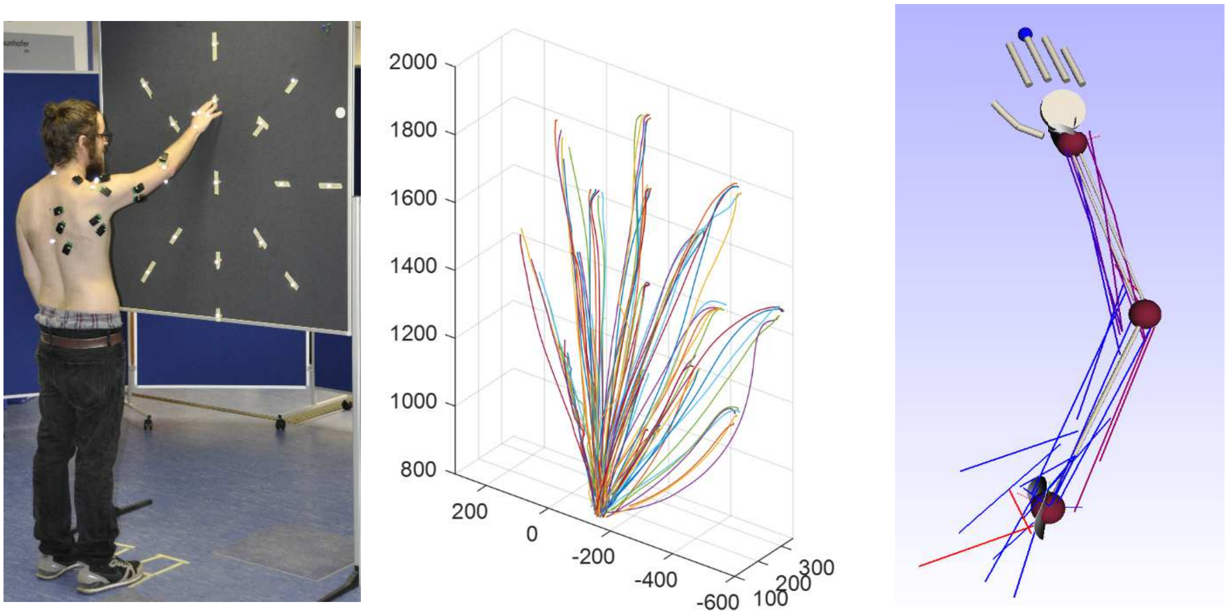

Fig. 1 *left*: the basic reaching test in the motion lab *middle*: measured hand trajectories for certain target points; *right*: simulation of a reaching task with our DHM arm Model (upper arm, forearm and hand modeled as rigid bodies (grey) connected via joints (5 DOF, red balls with grey ellipsoids delimiting the range of motion) and actuated by hill-type muscle models (blue and red lines, 29 muscles)

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