Towards bridging the gap between motion capturing and biomechanical optimal control simulations

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Abstract

Within this work, we make a first attempt towards combining motion capturing measurements of a human steering motion and optimal control simulations of this motion. We aim at investigating two widespread motion capturing technologies: optical systems, which are used under laboratory conditions due to the stationary camera infrastructure required, and inertial systems, which are solely based on body-worn inertial sensors and therefore enable ambulatory monitoring. From an optimal control point of view, the goal is to increase the realism of simulated human motion through measurements. From a motion capturing point of view, the goal is to compensate for measurement sparsity, errors or lacks through meaningful assumptions based on biomechanical simulation.

Concerning the measurement setup, optical and inertial measurements were captured during a steering motion from one male subject using commercially available systems (NaturalPoint OptiTrack, Trivisio Colibri Wireless). For this, retroreflective markers (including two rigid bodies) were attached to the right shoulder, upper arm, elbow, forearm and hand. Moreover, two inertial sensors were attached to the upper and forearm. For the simulation, the human arm was modelled as a multibody system consisting of three rigid bodies, whose dimensions are personalised for the subject. The optical marker positions were placed manually in the model based on measurements on the subject. An illustration of the model and the measurement setup used in this study are given in Figure 1. One possibility to find a specific

Figure 1: Left: human arm model used for optimal control simulations. Middle, right: Measurement setup showing the start and end position of the steering motion.

configuration trajectory $\boldsymbol{u}(t)$ and corresponding control force field $\boldsymbol{\tau}(t)$ of a multibody system between predefined start and end states is to formulate an optimal control problem (ocp)

$$\min_{\boldsymbol{u},\boldsymbol{\tau}} J(\boldsymbol{u},\boldsymbol{\tau})$$

subject to: · fulfillment of the equations of motion
· initial and final state conditions
· path constraints

In the ocp, an objective function J in minimised, while the optimisation variables $\boldsymbol{u}$ and $\boldsymbol{\tau}$ must fulfill the equations of motion and initial and final state constraints. There may be further constraints, like bounds on the control variables and path constraints (equality or inequality), e.g. to set limits on the joint angles according to anatomical restrictions. The ocp can be transformed with a direct transcription method into a finite dimensional constrained optimisation problem, which can then be solved using standard sqp algorithms. Herein, the optimisation variables are discrete quantities $\boldsymbol{u}_d = \{\boldsymbol{u}_n\}_{n=0}^{N}$ and $\boldsymbol{\tau}_d = \{\boldsymbol{\tau}_n\}_{n=0}^{N-1}$ defined at the time nodes $\{t_0, t_1, \dots t_N\}$. Instead of discretising the equations of motion in the ocp, we use a discrete version of the variational principle to derive a structure preserving time stepping scheme, see [1].

In the present study, as a first step, we investigate how the measured 3D positions of the optical markers can be included into the ocp at different levels of the problem formulation. In a first step, an objective function is formulated that minimises a weighted sum of the difference between the simulated marker positions $\boldsymbol{m}_s$, as given through the model, and the measured positions $\boldsymbol{m}_m$ and the control effort.

$$J_d(\boldsymbol{u}_d, \boldsymbol{\tau}_d) = \sum_{n=1}^{N} (\boldsymbol{m}_{m_n} - \boldsymbol{m}_{s_n})^T \cdot (\boldsymbol{m}_{m_n} - \boldsymbol{m}_{s_n}) + \omega \frac{\Delta t}{2} \sum_{n=1}^{N-1} \|\boldsymbol{\tau}_n\|^2$$

When the control effort is ignored, i.e. $\omega = 0$, this yields large and oscillating torques in the joints, see left hand part of Figure 2. When adding a weighted part of the control effort, i.e. $\omega > 0$, the resulting torques are much smoother (right hand part of Figure 2), furthermore the resulting motion looks more realistic.

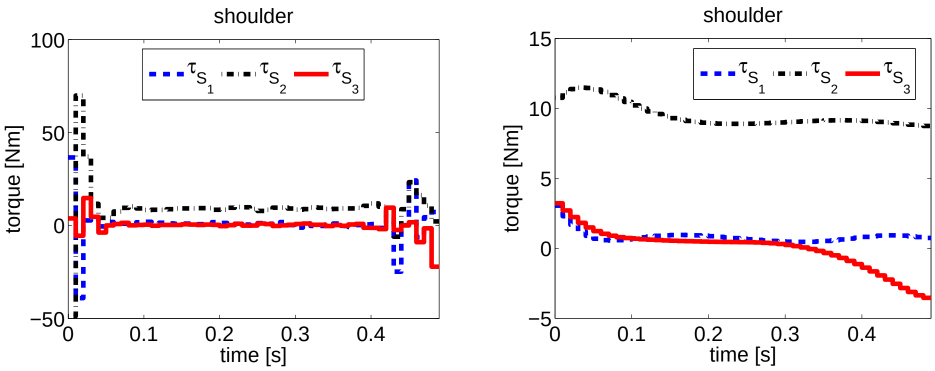

Figure 2: Left: Resulting joint torques in the shoulder with $\omega = 0$. Right: Resulting joint torques in the shoulder with $\omega > 0$.

This effect is investigated with further combinations of physiologically motivated parts of the cost functions. Moreover, cost functions that exclusively include physiological properties of the motion are tested, while the difference to the measurements up to a tolerance is included as an inequality constraint. By comparing the quality of the results as well as the efficiency of the optimal control simulations, we aim at finding an optimal procedure to combine motion capturing measurements and optimal control simulations.

As further steps, we plan to improve the mapping between the model and the measurement setup through functional calibration. Moreover, we plan to integrate inertial measurements in terms of angular velocities and accelerations into the cost function [2]. Accurate and robust inertial monitoring systems, which allow for ambulatory monitoring in uncontrolled environments, have a wide range of applications in the professional as well as the private sector, ranging from health and ergonomics [3] over human-machine-interaction to sports and games.

References

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