EMMA4Drive: A digital human model for occupant simulation in dynamic driving maneuvers

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EXTENDED ABSTRACT

1 Introduction

About two-thirds of all German workers currently commute to their workplace by car without being able to engage in any meaningful activity. In the future, occupants of autonomous driving vehicles will be able to perform new activities, such as regeneration exercises, working or consuming entertainment media. The goal of the EMMA4Drive project is to further develop the muscle-activated multi-body human model EMMA (Ergo-dynamic Moving Manikin) for use in next-generation partially or fully autonomous driving vehicles. The resulting software prototype EMMA4Drive will be able to analyse and evaluate safety and ergonomics equally during driving maneuvers under dynamic loads as a digital image of the occupant. To simulate the human driver in early stages of product development, digital human models (DHM) are widely used in automotive industry. Detailed finite element (FE) models of the human body are used to simulate the highly dynamic impact and resulting injuries in the human body in crash simulations [1]. DHM based on multibody system (MBS) kinematics are widely applied in reachability investigations and ergonomic assessment of the driver [2]. To predict active movement in dynamic driving maneuvers such as cornering, sudden braking, or lane change and pre-crash scenarios, neither FE nor simple MBS kinematic models are applicable. For a more detailed overview on DHMs in this application case, we refer to [3]. In this work, we will present an approach for the enhancement of a multibody based DHM to generate human like motions for a highly dynamic driving simulation.

2 Methods

The human is modelled as a multibody system, where the limbs are rigid bodies connected via joints. To actuate the system, hill muscles as well as joint torques can be used . An optimal control algorithm, which is able to handle opening and closing of contacts, is used in order to generate the dynamic human motion. In this approach, only some basic boundary conditions have to be prescribed. The interaction between the seat and the DHM is modeled with the help of model order reduction (MOR) [4] of detailed FEM models of the seat and the human. Using a certain objective function, the optimal control approach generates the desired control (muscle actuation) and the human motion. This approach has already been applied successfully to simulate dynamic motions of workers [5]. A time continuous optimal control problem (OCP) is defined abstractly by the following formulas:

$$\min_{\mathbf{q},\mathbf{u}} J = \int_I \phi\left(\mathbf{q},\dot{\mathbf{q}},\mathbf{u},\dot{\mathbf{u}}\right)\mathrm{d}t \tag{1}$$

$$\text{s.t.} \qquad \frac{\partial L}{\partial \mathbf{q}}(\mathbf{q},\dot{\mathbf{q}}) - \frac{\mathrm{d}}{\mathrm{d}t}\frac{\partial L}{\partial \dot{\mathbf{q}}}(\mathbf{q},\dot{\mathbf{q}}) + \mathbf{F}(\mathbf{q},\dot{\mathbf{q}},\mathbf{u}) + \mathbf{F}_{\mathrm{MOR}}(\mathbf{q},\dot{\mathbf{q}}) + \mathsf{G}^T(\mathbf{q})\boldsymbol{\lambda} = 0\,, \tag{2}$$

$$\mathbf{g}(\mathbf{q}) = 0\,, \tag{3}$$

$$\mathbf{b}_- \leq \mathbf{b}(\mathbf{q},\dot{\mathbf{q}},\mathbf{u}) \leq \mathbf{b}_+\,. \tag{4}$$

The variable $\mathbf{q}$ represents the temporal trajectory of the MBS and the control signals for muscles and joint torques are combined in the variable $\mathbf{u}$. In (1), the objective function J is introduced, where ϕ is a measure for the state of the system. As a side constraint, the constrained Euler-Lagrange equations (2)-(4) have to be fulfilled, where L represents the Lagrangian of the system, $\mathbf{F}$ the control forces and $\mathbf{F}_{\mathrm{MOR}}$ the force from the reduced interaction model. The function $\mathbf{g}$ summarizes the constraints of the dynamical system, $\boldsymbol{\lambda}$ is the corresponding Lagrangian multiplier and $\mathsf{G} := \frac{\partial \mathbf{g}}{\partial \mathbf{q}}$ the constraint Jacobian. Additional equality and inequality constraints can be included in the optimal control problem by the function $\mathbf{b}$ with corresponding lower ($\mathbf{b}_-$) and upper ($\mathbf{b}_+$) bounds. Altogether, the solutions of the OCP are temporal trajectories of the MBS $\mathbf{q}$, the control signals $\mathbf{u}$ and the Lagrangian multipliers $\boldsymbol{\lambda}$. In order to solve the optimal control problem, the continuous problem (1)-(4) is discretised into a non-linear problem using discrete mechanics, see [6] for more details. This approach is called DMOCC (discrete mechanics and optimal control with constraints). The discrete equations of motion derived in this way have been shown to be superior to standard discretisations since they preserve characteristics of the continuous system, such as conservation of momentum and good energy behaviour. This results in very stable integrators, which in practice allows for the use of large timesteps when solving the optimisation problem (1).

3 Application

In this work, we investigate two representative use cases. First, is a dynamic scenario with a rigid seat where the car suddenly breaks while no seat belt is active. Here, the DHM has to decelerate the mass of his upper body with both arms while the hands are grabbing the steering wheel. A snapshot after the first break impulse is shown on the left-hand side of Figure 1. An important note: The DHM movement is a solution of the simulation/optimisation process (1), where the trajectory of the car and the connection of the DHM to the car where the only inputs.

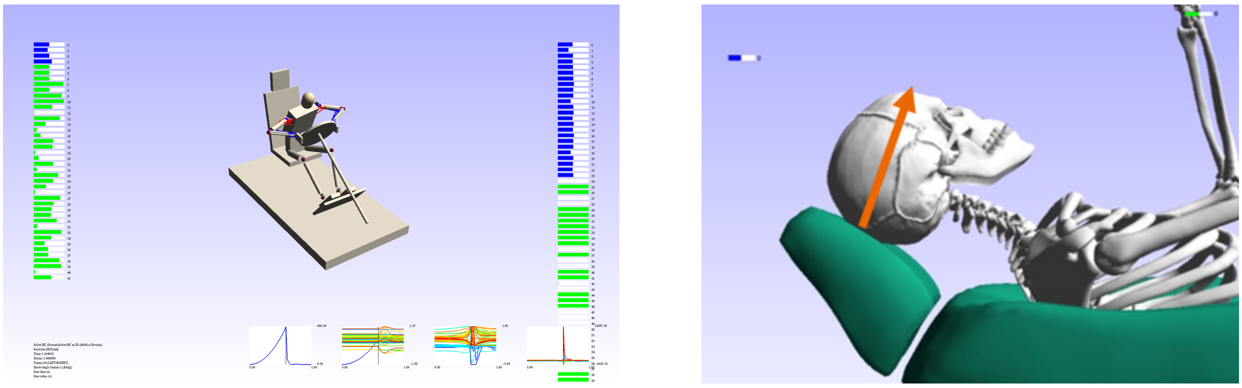

Figure 1: **Left:** Snapshot of sudden breaking simulation. **Right:** Simulation with MOR interaction between head and headrest.

As a second scenario, we investigated the interaction between the DHM and a flexible seat. Here, FEM simulation were performed to parametrize the MOR force $\mathbf{F}_{\mathrm{MOR}}$. With this force, we were able to run a OCP Simulation extracting the motion of laying down the head against the headrest. We have compared this motion with a simulation without the contact force. The result show that the OCP solver uses the MOR force to slow down the head and therefore reduce the control forces.

4 Discussion

In this work, the first results of the EMMA4Drive project are shown. First, we show an example of how to predict a motion of a human in a dynamic driving scenario with the optimal control framework based on DMOCC. Therefore, no tedious and time-consuming forward kinematic positioning of the manikin has to be performed. Additionally, all specified muscle forces and actuation signals are computed by this method as a by-product, which can be used in a further physiological evaluation. In a second simulation, we show a first feasibility study of how the complex interaction of the DHM and the seat could be integrated into the optimal control framework by MOR. In the future, we will use this method also for dynamic driving manoeuvres to get more realistic motions for new seating concepts in autonomous driving.

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