Simulation of a Standing Passenger during Driveaway using Optimal Control

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EXTENDED ABSTRACT

1 Introduction

As computing power increases and digital human models continue to evolve, they are increasingly being used for investigations in vehicle development and safety, e.g., in [1] [2]. While in the past mainly crashes and driver ergonomics were investigated, now also passengers of buses and trains are more in the focus of vehicle ergonomics and safety studies, as in [2]. Their investigation is more complex, since many more posture and movement variations must be considered. FEM models that are commonly used for crash simulations are currently not able to cover all interesting scenarios in this field, since the actuation capabilities of these models are still very limited and so far can be used mainly to maintain a given initial position. Optimal control of multibody systems allows the simulation of active motions and has already been successfully applied to various sports or lifting motions [3] [4]. This makes it a promising tool to simulate and analyze the motion and comfort of vehicle occupants during different driving maneuvers. In this work, which is part of the project "EMMA4Drive", we apply optimal control to simulate and analyze the occupant behavior in a departing bus.

2 Methods

The passenger is modeled as a rigid multibody system (MBS) with 40 degrees of freedom (34 actuated). The THUMS model of a 50th percentile male was used as a basis and transferred to a MBS using the kinematic structure proposed by [6]. Certain points in the structure were made movable by joints so that the model can reproduce the range of motion of a human being. The model is driven by three actuator models. The arms are each equipped with 29 line-type muscle models (including bi-articular ones) [5]. Muscle torque generators (MTG) [4] perform flexion and extension of the legs and trunk. The remaining joints, for which no MTG was available, are driven by simple torque sources. For the simulation of the passenger's behavior in a departing bus, a multi-phase optimal control problem (OCP) was set up and solved using the method of [5]:

$$\min_{\mathbf{q},\dot{\mathbf{q}},\mathbf{u}} \mathbf{J}[\mathbf{q},\dot{\mathbf{q}},\mathbf{u}] = \sum_{i=0}^{2} \int_{t_i}^{t_{i+1}} \Phi_i(\mathbf{q},\dot{\mathbf{q}},\mathbf{u})\mathrm{d}t \tag{1}$$

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

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

$$\mathbf{h}_i(\mathbf{q},\dot{\mathbf{q}},\mathbf{u}) \geq \mathbf{0}, \quad i = 0,1,2, \tag{4}$$

with $\mathbf{q}$, $\dot{\mathbf{q}}$ the position, velocity of the system, respectively. The activation of the actuation of the system is denoted by $\mathbf{u}$, which are also the controls of the OCP. The objective Φ describes the behavior of the passenger. The constrained Euler-Lagrange equation of the system is given by Eq. (2) with $\mathbf{f}$ the generalized forces, $\mathbf{G} = \frac{\partial \mathbf{g}}{\partial \mathbf{q}}$ the constraint Jacobian, and $\boldsymbol{\lambda}$ unknown force variables. Bounds on the variables and other constraints on the system are summarized in (3) and (4).

The phases of the OCP are as follows (Fig. 1 right): At the beginning of the first phase, the bus starts moving. The passenger has a

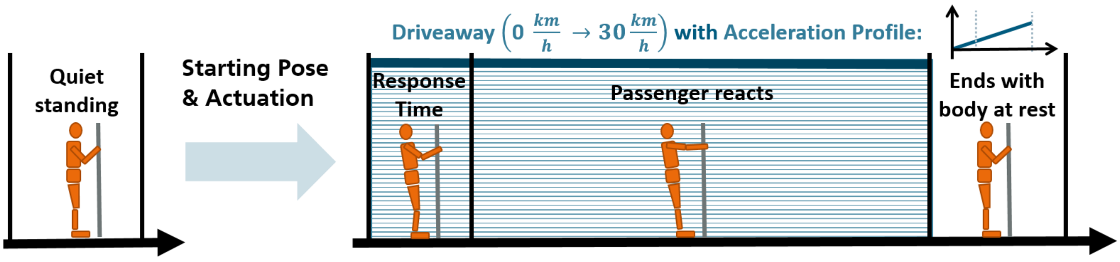

Figure 1: The simulation is organized in two OCPs. One calculates the starting position and actuation of the manikin (left) for the second OCP, which simulates the balance motion during the driveaway (right).

certain response time until it recognizes the changed conditions and reacts to them. To simulate this, the actuation of the manikin cannot change during this phase. During the second phase, the manikin is allowed to react to the accelerations. The phase ends when the desired target speed of the bus is reached. In the third and final phase, the manikin should return to a stable position. A second OCP (Fig. 1 left) was set up to compute a steady stance under various constraints on the posture, e.g., regarding the arms. The calculated joint positions and actuation were adopted as starting condition in the previous described OCP.

3 Results

The simulation was performed with two different stance configurations of the manikin, one oriented in the direction of driving (I) and the other opposite to the direction of driving (II). In both cases, the starting joint angles and actuation were the same. A linearly increasing acceleration profile (jerk: $0.3\ g/s$) was applied until the vehicle reached a speed of 30 km/h. Via the OCP, the actuation and movement of the manikin was calculated to compensate for the acceleration in a energy-efficient manner while maintaining the position of the arm that holds onto the handrail to a certain extend. Higher hand contact forces occurred in Scenario I (avg. 72 N and max. 159 N vs. avg. 53 N and max. 109 N). However, the actuation required to compensate for the driveaway is significantly less when the manikin is facing the direction of driving and is pushed backward than when it is pushed forward against the handrail (40% less actuation in the arms and 28% less actuation in the remaining joints). During Scenario II, some muscle were even almost fully activated whereas in I, the maximum observed activation was 60%.

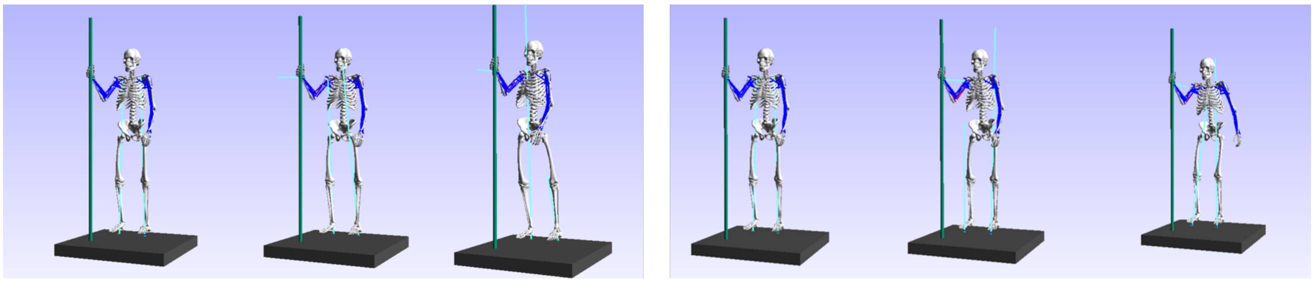

Figure 2: Snapshots of the simulated motions (left: facing driving direction; right: facing opposite direction) at 0 s, 0.5 s, and 1 s.

4 Discussion & Conclusion

This methodology can be used to simulate and analyze the behavior of standing passengers during various driving maneuvers. The knowledge gained in the simulation can be used as guidelines for the driving behavior of bus or train drivers and vehicle assistance systems to make public transport safer and more comfortable. The application of the acceleration profiles is variable and can be replaced by more complex profiles than the ones shown here. Different balancing strategies can be simulated by changing the objective function. By swapping the starting position of the manikin, the influence of different poses on the actuation required to compensate for the same driving maneuver can be studied. In future work, we plan to validate our simulation results against experimental data.

Acknowledgments

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References

[1] T. D. Tran, J. Holtz, G. Müller and S. Müller. Validation of MADYMO human body model in braking maneuver with highly reclined seatback. International Journal of Crashworthiness, 27(6):1743-1752, 2022.

[2] J. Ambrósio, M. Carvalho, J. Milho et al. A validated railway vehicle interior layout with multibody dummies and finite element seats models for crash analysis. Multibody System Dynamics, 54:179–212, 2022.

[3] K. A. Keaton, C. Brown, W. McNally, C. Jansen and J. McPhee. Muscle torque generators in multibody dynamic simulations of optimal sports performance. Multibody System Dynamics, 50(4):435-452, 2020.

[4] M. Millard, A. L. Emonds, M. Harant and K. Mombaur. A reduced muscle model and planar musculoskeletal model fit for synthesis of whole body movements. Journal of Biomechanics, 89:11-20, 2019.

[5] M. Roller, S. Björkenstam, J. Linn, and S. Leyendecker. Optimal control of a biomechanical multibody model for the dynamic simulation of working tasks. In ECCOMAS Thematic Conference on Multibody Dynamics, Prague, Czech Republic, June, 2017.

[6] P. Beillas et al. PIPER EU Project Final publishable summary. 2017.