PARAMETER INDENTIFICATION OF A WOBBLING MASS MODEL BY MEANS OF DROP JUMPS

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The variously motivated requests of biomechanics regarding the simulation and analysis of the human movement and the associated better understanding of mechanisms of the human neuromuscular skeleton system has led to the development of realistic 3D-man models. Biomechanical multibody systems as models for moving biological systems (humans, animals) have to incorporate more difficult system components than technical systems. Among others, the flexibility of the individual body segments due to muscles, tendons, ligaments, organs and body fluids has significant influence. The objective of this work is the parameter identification of these so-called wobbling masses.

KEY WORDS: biomechanical modelling, multibody system, wobbling mass, ground contact model

INTRODUCTION: Segments of the human body generally do not consist of one homogeneous mass, but are composed of several single masses with different properties. Depending on these properties, within each segment, a rigid part and a soft part can be distinguished, movable with respect to one another. In the model it is assumed, that the mobile soft parts are positioned outside at the extremities and inside at the trunk. Both, the soft and the rigid part are modelled by a rigid body in a segment.
The ability of the wobbling mass to move with respect to the bone is considered as a joint with degree of freedom n=6, which connects the centers of mass of the rigid and soft part of the segment. The motion of the wobbling mass is restricted by physical coupling, which represents the restoring force of connective tissues – like skin or tendon – after elongation.

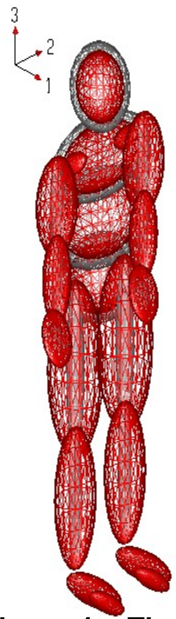


Figure 1 – The model

METHODS: The modelling is based on several assumptions. They are as follows: (a) the wobbling mass is moving with respect to the bone, (b) in the nominal position, the centers of mass of the wobbling mass and of the bone coincide in the center of mass of the original rigid segment given by a standard man model, (c) the centers of mass of the wobbling mass and the bone are connected by physical coupling, and the restoring force between the wobbling mass and (d) the bone is assumed to be linear visco elastic:

$$F = -c * s - d * v .$$

Here **c** and **d** describe material properties, **s** is the elongation and **v** is the velocity. **c** and **d** can be determined by means of measurements basing on the mathematical model of a linear oscillator, where the motion of the wobbling mass is recorded with and without a defined additional mass. If the frequencies with additional mass, without additional mass, and the logarithmic decrement p (ratio of two elongations of the measured curve) are known, **c**, **d,** and the real wobbling mass (m) can be calculated.
Generally, for the measurements of the unknown frequencies it is assumed, that the single parts of a wobbling mass are not independent of each other with respect to their dynamic behavior, because they are connected by connective tissues. Therefore, an oscillation which occurs in one structure should be transferred to other structures.
This leads directly to the assumption that oscillations, which occur in more deeply located structures can be measured at the surface of the skin. Drop jumps are used because of their simplicity and preclude the need for special technical accomplishment on the part of the tested person. They also provide an exercise where high accelerations occur to provide such

oscillations necessary for the measurements. During drop jumps performed with a height of 40 cm, the following quantities were measured which included the ground reaction force, the angles of ankle, knee, and hip as well as the acceleration of the wobbling mass which is measured at the surface of the skin. These measurements have been performed by the Institute for Applied Training Science Leipzig and the Institute of Human Movement Science and Training (Prof. Krug) at the University of Leipzig (Germany) and were focused on the longitudinal motion of the wobbling mass at the femoral. Therefore, the degree of freedom between the soft and the rigid part is reduced to n=1 by kinematic coupling.
The height of the jump and the time history of the inner coordinates (relative coordinates of the ankle, knee, and hip) of the drop jump are the input data for the simulation using the simulation-tool alaska.
For a realistic simulation of the landings the man model was upgraded with a ground contact model. Two points were defined under each foot representing the ground contact points under the heel and the ball of the foot. These points are used to apply ground reaction forces depending on the penetration depth and its velocity.
The force law of the ground reaction force is determined in a way that a penetration depth of 1 cm representing the flexibility of the foot arch and the heel pads during landings can not be exceeded.
Results of the simulation are shown by the ground reaction force and the behavior of the femoral wobbling mass along the longitudinal femoral axis.

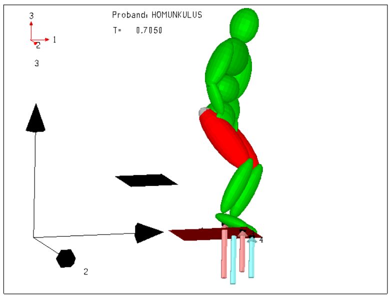


Figure 2 – The landing.

RESULTS AND DISCUSSION:

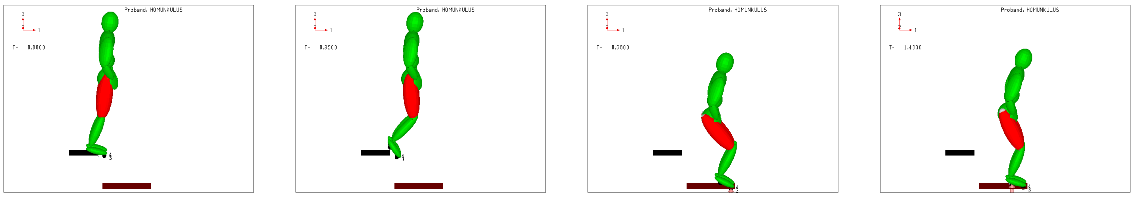
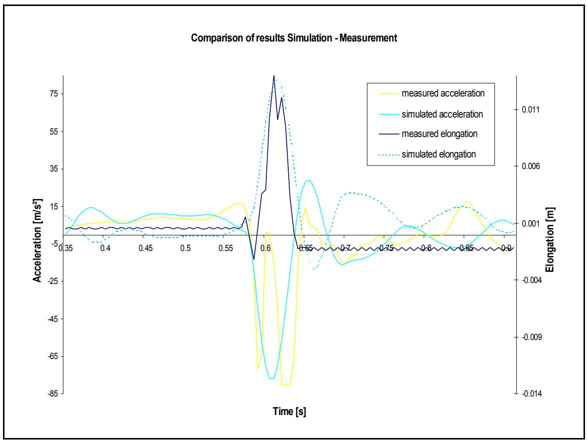


Figure 3 - Simulated drop jump.

The stiffness and damping parameters are:

$$c = 4491.4 \text{ [N/m]} \qquad \text{and} \qquad d = 40.5 \text{ [Ns/m]}.$$

As a measure of the approximation quality of the simulation results, the minima and maxima of the acceleration and the elongation of the wobbling mass are calculated as well as the ground reaction force. Beside these results, the frequencies of the wobbling mass, the correlation coefficient, and the relative deviations of the ground reaction force and the acceleration are used for the evaluation.
The measured acceleration has a maximum value of 19.5 m/s² and a minimum value -74.6 m/s², while the simulation leads to a maximum value of 17.5 m/s² and a minimum value of –80.3 m/s².
For the first elongation of the wobbling mass 1.12 cm is measured using the videometry of high-speed recordings, that agrees with the result of the simulation (1.4 cm). But the second elongation of the wobbling mass can not be quantified because of the 2-dimensional video recordings. During the landing the wobbling mass performs a large rotation around the longitudinal axis of the femoral, therefore in this phase the marker position can not be located. The result of the simulation is -0.3 cm.
The maximum of the simulated ground reaction force amounts 2626 N in comparison to the measured maximum of 2538 N.



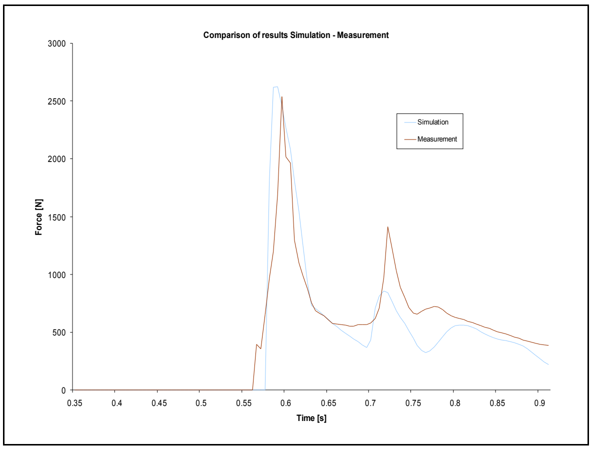


Figure 4 - Elongation and acceleration. **Figure 5 - Ground reaction force.**

The frequency of the acceleration is 11 Hz in the simulation and 12 Hz for measured data. The correlation coefficients related to the ground reaction force, the acceleration and the path are 0.9, 0.55, and 0.88 respectively.
In addition to the correlation coefficient a ratio of integral deviation between measurement and simulation is used to judge the quality of the identified parameter. This ratio is defined as follows:

Area of deviation: $$F_1 = \int_0^T |Y_1 - Y_2|\, dt$$

Sum of both areas: $$F_2 = \int_0^T (|Y_1| + |Y_2|)\, dt$$

Ratio of deviation: $$0 \le \frac{F_1}{F_2} \le 1$$

with: Y_1: simulation data, Y_2: measurement data.

For the ratio of deviation a value of 0.14 is calculated for the ground reaction force, 0.43 for the acceleration and 0.31 for the path – in the sequence with measured data.

CONCLUSIONS: Considering the results of the ground reaction force, it follows that use of the ground contact model demonstrates a ground reaction force close to reality, which can be used as base for the simulation.
With respect to the motion of the wobbling mass the results have fewer expressiveness. The comparison between simulated and measured elongation shows a good agreement, whereby this statement is only valid for the first elongation, which is measured. The acceleration shows a good agreement with respect to the maximum, minimum and the frequency. But the correlation coefficient and the ratio of deviation indicates an insufficient agreement. Probably, this divergence results from the short-time high deviation of the measurement data versus the simulated data at the maximum elongation. On one hand measurement problems could explain the discrepancy, on the other hand it could also be the activity of the participating muscles inside the inspected wobbling mass. The electromyography of the M. vastus medialis and M. rectus femoris shows at this time an increased activity. It should be the target of further studies to determine which reasons lead to the existing deviations between the measured and simulated data.

Table 1 Results of the Wobbling Mass Tests

Statistical Value	Ground reaction force [N]		Acceleration [m/s²]		Elongation [cm]	
	Simulation	Measurement	Simulation	Measure-ment	Simulation	Measure-ment
Maximum	2626	2538	17.5	19.9	1.4	1.12
Minimum	0	0	-80.3	-74.6	---	---
Frequency	---	---	11 Hz	12 Hz	---	---
Correlation coefficient	0.9		0.55		0.88	
Ratio of deviation	0.14		0.43		0.31	

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