Prediction of Discomfort During Arm Movements

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Abstract. On the way to a generalized discomfort model for movements steps are presented that calculate the determining parameters for the model. Discomfort is mainly dependant on posture and relative torque. A multi body system arm model is used to calculate the driving torques of a lifting task using inverse dynamics. A motion analysis of the movement was carried out and the corresponding angles were used to drive the arm model. In order to calculate relative torque a torque velocity relationship according to Hill was implemented in the arm model.

1 Introduction

In the field of ergonomic design the concept of discomfort is gaining more importance. Car manufacturers are aiming to predict the discomfort of customers performing typical tasks in and around the car, e.g. closing the door, pulling the hand brake or lifting a beverage crate out of the car boot. In the planning process of an assembly line the inner forces and moments of the worker are of interest in order to estimate if this work can be performed over a period of time. Recent studies investigated the ingress/egress movement. Relevant measures for the analysis of this movement are reactive joint forces, muscle effort [1] and discomfort [2]. Cherednichenko [3] examined the car ingress with the concept of leading body parts that control the movement. He used a force based method to simulate the dependant body parts which was applied to the human model RAMSIS. In order to analyze movements for the optimum ergonomic design process kinetic values like joint moments performed by a human during a specific task need to be calculated. This implies the use of inverse dynamic calculations.

Preliminary work on a strength based discomfort model for posture and movement was done by Zacher [4] at the Lehrstuhl für Ergonomie at the Technische Universität München. The aim is to develop a generalized discomfort model for movements of the whole body with the aim of predicting discomfort for different anthropometries and tasks. The results can be implemented in an existing digital human model like RAMSIS. Focusing first on the arm system knowledge about the static conditions of the model will be assigned to dynamic conditions.

This report will provide the necessary steps from movement analysis to the calculation of inner joint moments which are essential parameters in our approach of describing discomfort.

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2 Experiment

The process was performed with a survey of an arm movement. The task of the subject (male, height: 188cm, weight: 102kg) was to lift a weight (10.5kg, 75% of the individual maximum weight) from a table to a platform. The table was adjusted to a height that the angle of the elbow was roughly 90°. The subject was instructed to keep the contact with the backrest and not to move forward with the trunk, so that the arm movement was not influenced by the movement of the spine. Two cameras were used to film the movement. Pictures with a frame rate of 25 HZ were saved to the hard disk. The motion was analyzed with the PCMAN [5], [6] measuring system. After the calibration of the system it is possible to superimpose the PCMAN model with the camera pictures (Fig. 1). First the segment lengths of the right clavicle, upper arm and fore arm were adjusted to the subject with the superimposition method. Afterwards the posture of the initial frame of the movement was adapted and than each successive frame was adapted by the motion tracking module. The algorithm tracks the complete movement automatically when the lifting height is 88mm and the movement is performed slowly as in this example (Fig. 2). In another configuration with a lifting height of 434mm the tracking has to be stopped when a drift occurs as the algorithm is not robust over a longer time. The next posture has to be adapted manually, so that the tracking turns into a semi automatic procedure.

Only the clavicle, shoulder and elbow joints were considered during the tracking. The angles of the wrist were only adapted for the initial frame and stayed constant afterwards. The algorithm was not accurate enough to detect axial rotations in the elbow or the small angle changes of the hand. The angles for each degree of freedom were saved in a text file.

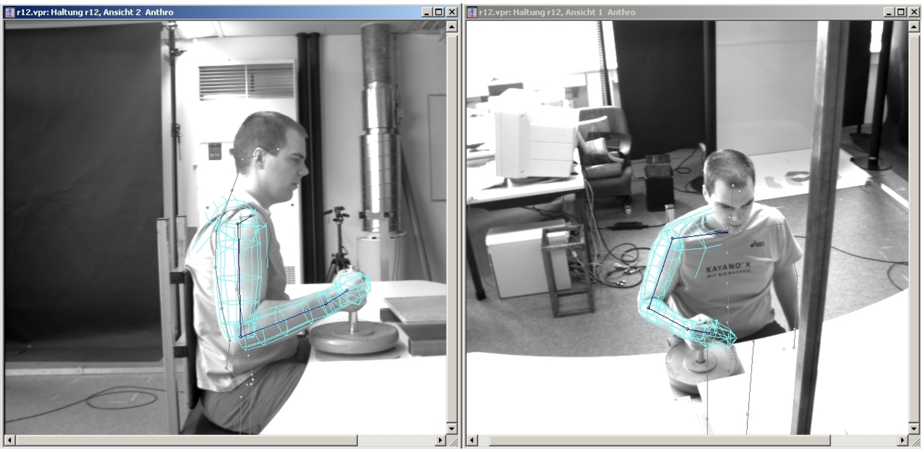

Fig. 1. Initial frame of the PCMAN motion tracking

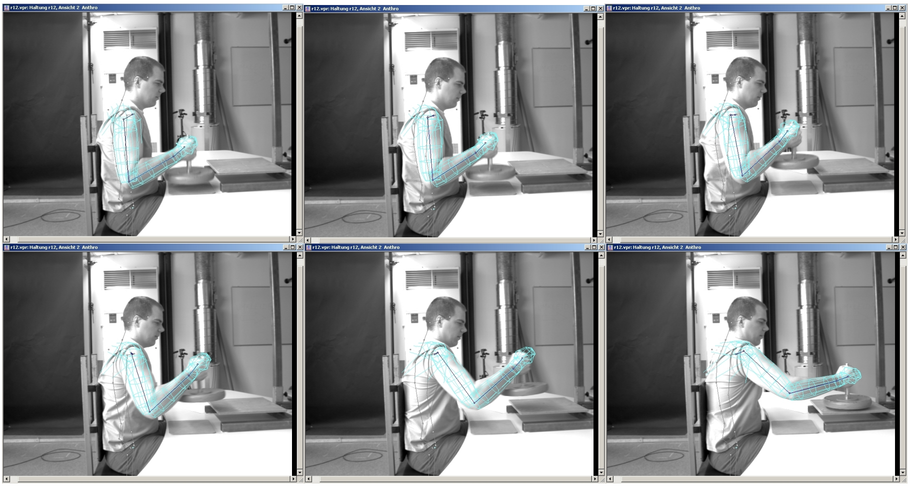

Fig. 2. Single images of a time sequence showing the lifting task

3 MBS Model DYNAMICUS

The software alaska is a toolbox for modeling and simulation of mechatronic systems developed by the Institut für Mechatronik at the Technische Universität Chemnitz. DYNAMICUS is a biomechanical multi body model [7]. It provides an interface with RAMSIS, so that posture and anthropometry of a RAMSIS model can be transferred to the MBS model. This means all joint angles, the mass of each body segment, the center of mass and the distance to the next joint in the kinematical chain. In the current version 5.0 of the software only the moments of inertia are calculated from the anthropometric model of Saziorski. Both digital human models are shown in Figure 2. The DYNAMICUS model used in this case consists of a constrained trunk, which is the basis of any model und serves as a linking to the arm system. Consequently, the human arm model consists of the clavicle, upper arm, fore arm and the hand. The DYNAMICUS Bibliography provides a variety of modeling components for each segment that differs in the room of movement (e.g. spherical and planar rotation, fixation). For the use of the RAMSIS interface special components are prepared that comply with the kinematical structure of the RAMSIS model. The hand joint is fixed as well as the axial rotation of the elbow as the motion tracking didn't detect these DOFs. Also the axial rotation of the clavicle joint is constrained as this motion is not physiological. A mass of 10,5kg was fixed to the hand at a distance that corresponds to the length of the handle of the weight that the subject lifted during the experiment.

Although both models have the same kinematical structure, the local coordinate systems and the representation of the rotations in the joints differ. So the matrix representation in each joint for the positions in each time step had to be calculated using

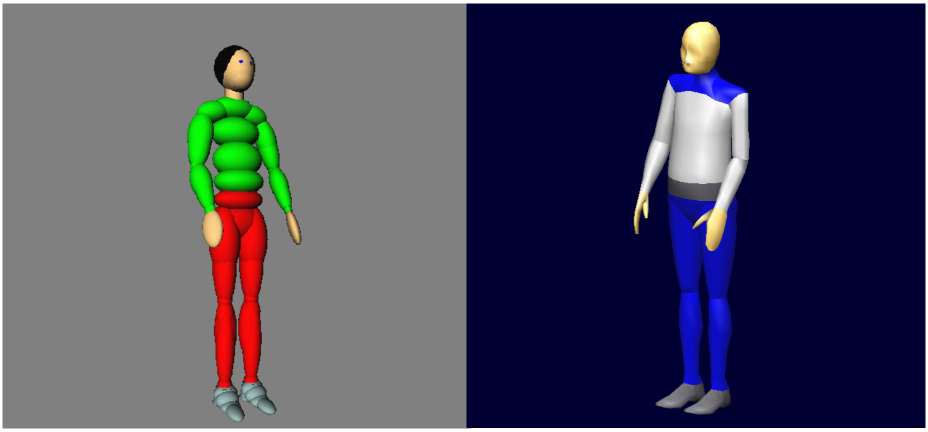

Fig. 3. The biomechanical multi body model DYNAMICUS (left) and the digital human model RAMSIS (right)

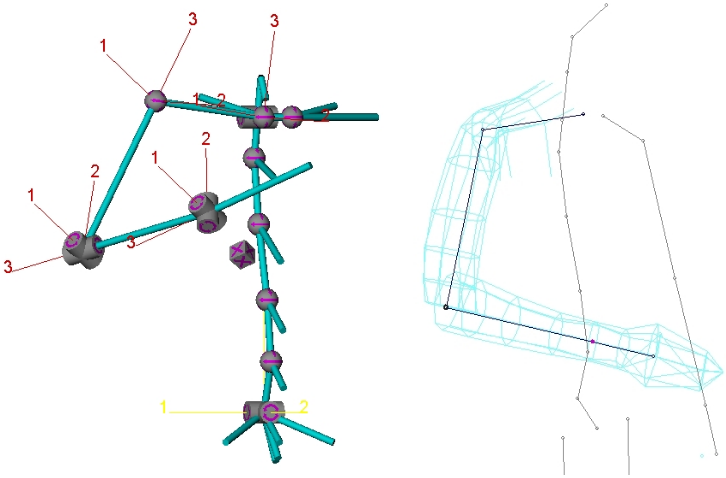

Fig. 4. Kinematic structure with connections between the joints of DYNAMICUS and RAMSIS

Matlab routines. The cardan angels and their derivatives were imported into the DYNAMICUS arm model. Thus the movement of the human arm system could be described providing the time dependant behavior of the joint angles. This temporal control is realized in the way that constraints are added to the model equations.

The torques resulting from the control of the joint angles that drive the simulation are important for further evaluation as well as the maximum torques that the subject is able to apply in each position. The maximum torques M_0 of the subject were measured by Zacher [4] under static conditions. The force velocity relationship of the muscles and consequently of the resulting torques are taken into account by implementing a Hill type function. The parameters for the hyperbolic function [8] describing the torque velocity relationship for concentric torques are taken from de Koning [9] who measured the angular velocity under different loads for the elbow flexors of untrained but sports minded males.

$$M = \frac{(M_0 + a) \cdot b}{(\omega + b)} - a \tag{1}$$

Using this equation the maximum concentric torque M of a DOF of a joint is calculated at the actual angular velocity ω of the movement. This is done for all joints and their respective DOF with the constants a=76 Nm and b=14 rad/s. In the eccentric phase the hyperbola was calculated according to Yeadon et al [10]. The composite function is continuous and there appears a ratio in the slopes of the eccentric and concentric function at ω=0. This slope factor is k=4.3.

4 Preliminary Results

First and intermediate results of the simulation of a lifting task are presented on torques, maximum torques and the relative torques (relation between both). This is an intermediate step to calculate discomfort during arm movements. Fig. 5 depicts the kinematical values joint angle and angular velocity of the shoulder elevation along the transversal axis. The upper arm is continuously lifted to the final height. The angular velocity shows a typical bell shaped form, resulting from the acceleration of the weight and the deceleration in the phase of placing the object to the final position. Both local maxima of the velocity curve result from a polynomial fit to the numerical derivative of the angles. Flexion angle and velocity of the elbow are shown in Fig. 7. First the elbow is slightly flexed in order to lift the weight in vertical direction and keep a security distance to the platform. Afterwards the elbow is extended to place the weight in the middle of the platform. During the extension the flexor muscles produce an eccentric flexion torque that is opposed to the direction of the velocity (negative velocity and positive torque). Fig. 6 depicts the maximum torque calculated from Hill's equation (Eq. 1) that is dependant on the velocity and the maximum isometric torque at the respective posture. The dotted curve is the isometric maximum torque from experiments with the subject. When ω=0 both curves are identical.

At positive velocities (shoulder: elevation, elbow: flexion) the muscles are able to produce a concentric torque that is less than the maximal isometric torque. At negative velocities like at the elbow in Fig. 7 the eccentric torque is higher than the isometric torque (Fig. 8). The step in the slope of the maximum torque is due to the slope factor of the composite Hill curve. The produced torques in shoulder and elbow (Fig. 6 and Fig. 8) are always positive as the weight is moved against gravity.

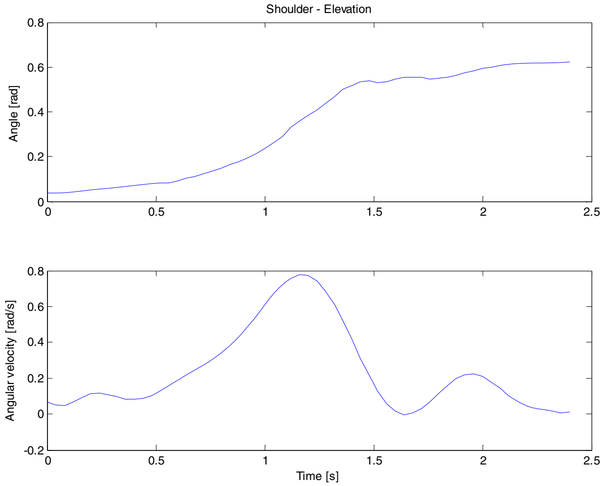

Fig. 5. Plots for the shoulder elevation along the transversal axis. Displayed are the angle and the angular velocity during the lifting task.

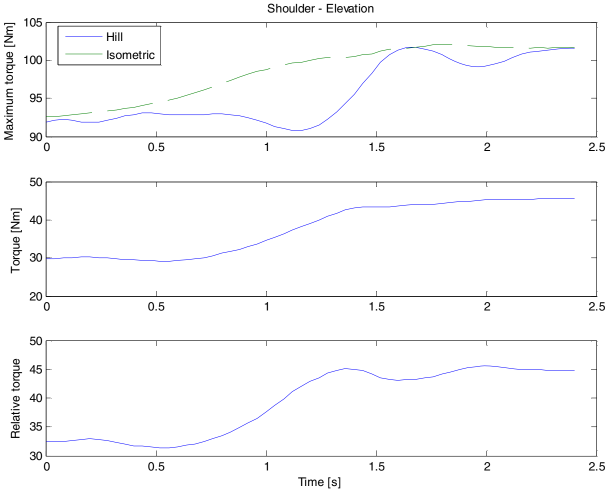

Fig. 6. Plots for the shoulder elevation along the transversal axis. The maximum torque at each time step/posture is given for the isometric condition (- - -) and for the concentric condition calculated with Hill's equation (---). Displayed are also the torque and the relative torque.

Relative torque is the ratio between maximum torque and actual torque in the respective direction of motion in the joint. This is a parameter that influences the discomfort.

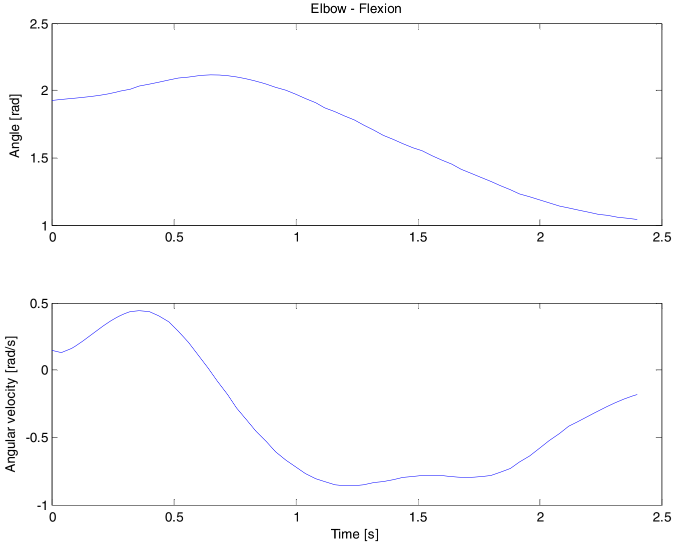

Fig. 7. Plots for the elbow flexion. Displayed are the angle and the angular velocity during the lifting task.

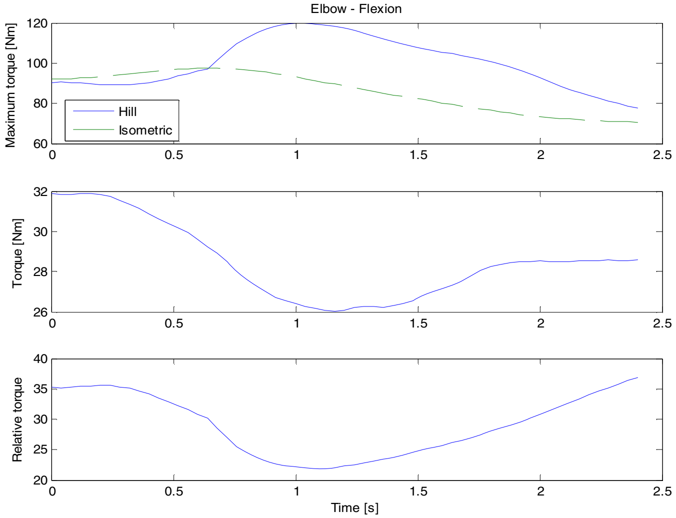

Fig. 8. Plots for the elbow flexion. The maximum torque at each time step/posture is given for the isometric condition (- - -) and for the concentric/eccentric condition calculated with Hill's equation (---). Displayed are also the torque and the relative torque.

5 Discussion and Conclusion

On the way to a generalized model to predict discomfort during movement intermediate results were generated. These results are parameters on which a discomfort model will be dependant. The discomfort is a subjective value, but as it can be evaluated with other factors that are connected with the concept of suffering it is possible to describe discomfort with physical values. These values act on the body or within the body like posture, force/torque and pressure from the contact with the surrounding. Thus we focus on two parameters that influence the local discomfort in a joint. These are joint angles and the relative joint torque. A posture and force dependant articular discomfort model for static conditions was presented by Zacher [4], Schäfer [11] and Wang [2]. If the local discomfort model is also applicable for movements needs to be shown by calculating the discomfort with the arm model and comparing the results with the discomfort ratings of the subject. It will also be interesting to find out if the time is another factor to influence the discomfort of movements as assumed by Wang. This would be similar to the physical demand of dynamic muscle work. Our aim is to give an objective evaluation of discomfort during movements.

References

1. Rasmussen, J., Christensen, S.T.: Musculoskeletal Modeling of Egress with the AnyBody Modeling System. In: Proceedings of the SAE DHMS 2005, Iowa, 2005-01-2721 (2005)
2. Dufour, F., Wang, X.: Discomfort Assessment of Car Ingress/Egress Motions using the Concept of Neutral Movement. In: Proceedings of the SAE DHMS 2005, Iowa, 2005-01-2706 (2005)
3. Cherednichenko, A., Assmann, E., Bubb, H.: Computational Approach for Entry Simulation. In: Proceedings of the SAE DHMC 2006, Iowa, 2006-01-2358 (2006)
4. Zacher, I., Bubb, H.: Strength Based Discomfort Model of Posture and Movement. In: Proceedings of the SAE DHMS 2004, Rochester, 04DHM-66 (2004)
5. Seitz, T., Balzulat, J., Bubb, H.: Anthropometrie and Measurement of Posture and Motion. International Journal of Industrial Ergonomics, 25, 447–453 (2000)
6. Seitz, T., Bubb, H.: Human-model based movement-capturing without markers for ergonomic studies. In: Proceedings of the SAE DHMC 2001, Arlington, 01DHM-7 (2001)
7. Benutzerhandbuch DYNAMICUS alaska 5.0. Institut für Mechatronik, Reichenhainerstr. 88, 09126 Chemnitz, Germany
8. Stern Jr, J.T.: Computer Modeling of Gross Muscle Dynamics. Journal of Biomechanics 7, 411–428 (1974)
9. de Koning, F.L., Binkhorst, R.A., Vos, J.A., van't Hof, M.A.: The force-velocity relationship of arm flexion in untrained males and females and arm-trained athletes. European Journal of Applied Physiology 34, 89–94 (1985)
10. Yeadon, M.R., King, M.A., Wilson, C.: Modelling the maximum voluntary joint torque/angular velocity relationship in human movement. Journal of Biomechanics 39, 476–482 (2006)
11. Schäfer, P., Zacher, I.: On the way to autonomously moving manikins – empowered by discomfort feelings. In: Proceedings of the XVI. World Congress on Ergonomics of the IEA, Maastricht (2006)