SOME PRINCIPLES OF ADEQUACY CRITERIA FORMULATION IN HUMAN MOTION ANALYSIS

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INTRODUCTION: Motion recording systems allow us to monitor the trajectories of markers, their speed and accelerations, as well as external constraint reaction forces values. However, assessment of values of controlling SMA motion muscle forces and corresponding energy expenditures is possible only through the employment of mathematical and computer models of the observed SMA motion (an anthropomorphic model (AM)). The number of parameters of AM, which simulates real human motion, can be as high as one hundred or higher. This makes obvious the necessity of real object and model adequacy criteria formulation. The optimal value of such criteria should indicate structural and parametric adjustment of AM to certain real human motions. The choice of these parameters values seriously depends on what experimental data is available.
Experimental data reliability grows if there is available redundant information on dependent variables obtained through independent channels. Thus, there is an obvious necessity of formulation and investigation of such criteria which would allow us to assess model quality and consequently the adequacy of experimental results analysis employing this model. The aim of the research is to develop principles and methods of adequate biomechanics model construction with dynamic and kinematic experimental data taken into account.

METHODS: The mechanical model was based on a description of AM as a system of solid bodies linked together by multi-degree generalized joints and/or interacting according to a given law. It is supposed that motion takes place as a result of the action of external forces, controlling muscles forces and constraint reactions. As motion constraints we can use kinematic equations (trajectories of separate points, mutual rotation of SMA elements, generalized velocities and acceleration behavior equations) as well as force factors (support reaction force, measured forces in control points, etc.). The basis of the computer model consists of a system of differential-algebraic equations of motion of a ramified kinematics chain with non-stationary constraints [1]. Motion which satisfies some set of conditions can be synthesized by the solution of direct problems of the dynamics of solid bodies systems. This model motion allows us to describe the trajectories of any number of markers and support reactions and controlling moments. A generator of random values allows us to distort any of the obtained data with a given probability distribution law. Then, processed as "experimental", these data serve as input data for the calculation of inter-element forces and moments. The difference between forces calculated by the solution of inverse problems of dynamics and initial data can serve as criteria of identity of the "observed" and model processes. Variation of probability distribution law parameters allows us to undertake imitative modeling of experiments and to assess SMA model sensitivity to measurement errors during motion recording and the quality of data obtained on the basis of the model. On the other hand, in the framework of the imitative modeling method, one can also vary model GMIC parameters which would most correspond to recorded motion data. Finally, experimental simulation allows us to determine the number of SMA degrees of freedom which is best for modeling and processing for a given class of motions. Such an approach allows us to determine the main dynamic values, including generalized forces. Measurement errors lead to significant errors in assessed values of inter-element forces and moments and especially the values of external with respect to AM reaction and total moment of external forces in the support phase of motion. Variation of AM elements parameters, positions of joints, smoothing parameters of trajectories allows us to obtain an averaged assessment of external force values. The paper presents a new iterative approach to the structural and parametric adjustment of AM. The presence of non-stationary constraint equations allows one to use some of the experimental data for such constraints.

RESULTS: One result of the investigation is that we have analyzed grand circles on the horizontal bar with a following jump off the bar and four backward somersaults performed in a grouped position. Grand circles on the horizontal bar can serve as one of the most revealing examples of small displacements influence. Due to the necessity to differentiate experimental data, attempts to take into account the motion of the bar lead to large values of the first inter-element moment M_1 (the moment between the palm and the bar). Let us note that absolute error in the determination of joints coordinates is of the same order for all joints. However, joint angle value error is in inverse proportion to the distance between the joints. The most interesting is analysis of bar position error influence on values of inter-element moments. As experimental data we used the results of backward grand circles synthesis for the 3-element model, whose kinematic scheme is presented in Fig. 1. Synthesis of grand circles was carried out by presetting the hip joint angular displacement. Synthesized values of inter-element moments are presented in Fig. 2 (M_1 = 0). Synthesized "accelerating" circle and additional data on bar reaction force behavior were used for testing the analysis problem solution. It was adopted that joints coordinates data is distorted by equally distributed (within a circle of given diameter) noise. Results of the optimization procedure (for frames frequency of 20 frames per second) are depicted in Fig. 3. Optimal parameters values have been received for the adequacy criterion

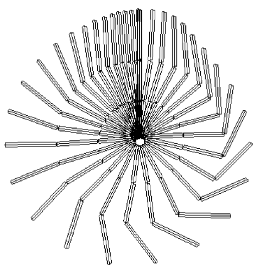

Fig. 1

$$J=\int_{t_0+t_1}^{T-t_1} \{\lambda_1 (x_1 - x_{1*})^2+\lambda_2 (y_2 - y_{2*})^2\}\, dt + \int_{t_0+t_2}^{T-t_2} \{\lambda_3 (v_{x1} - v_{x1*})^2+\lambda_4 (v_{y2} - v_{y2*})^2\}\, dt$$

$$+ \int_{t_0+t_3}^{T-t_3} \{\lambda_5 (w_{x1} - w_{x1*})^2+\lambda_6 (w_{y2} - w_{y2*})^2+\lambda_7 (M_1 - M_{1*})^2\}\, dt$$

with $\lambda_7 \neq 0$. These results could be considered as satisfactory. But if the criterion is used with $\lambda_7=0$, optimal values of smoothing parameters give the best result for the reaction force discrepancy, although they yield essentially less exact values of inter-element moments. As one of the reasons for such unsatisfactory smoothing we see low frequency of displacements registration. An important advantage of the

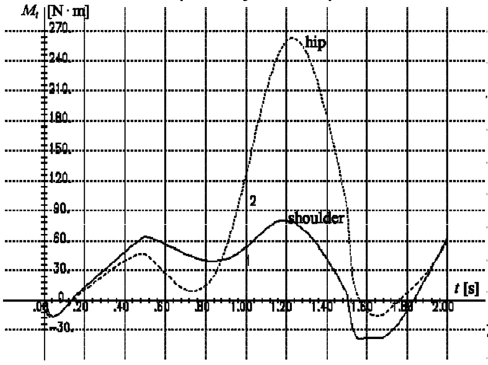

Fig.2

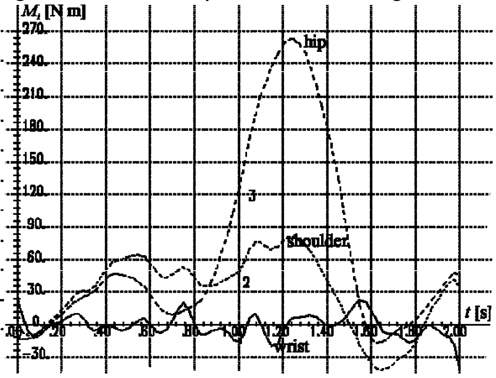

Fig. 3

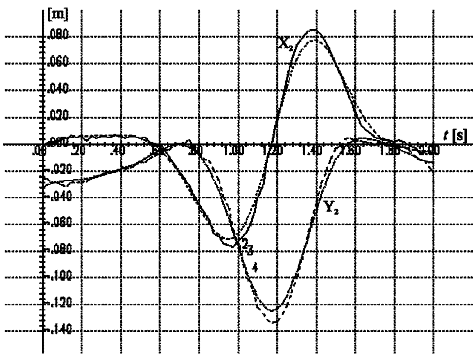

Fig. 4

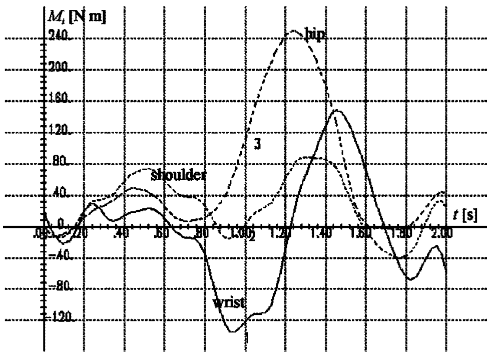

Fig. 5

considered analysis example is the possibility of variation of "measurements" parameters in order to estimate the significance of errors of different parameters groups in the calculation of inter-element moments. Thus, by GMIC variation it can be seen that their measurement error is about 10 times less "important" than that for velocities and accelerations of given displacements. We also found that an essential error in moments calculation is due to the instability of the registration frequency, which can be easily explained by distortion of the whole kinematic picture. Most significant errors appeared in data on the horizontal bar position. Simulation of such errors can be easily done by increasing the lower boundary for values of smoothing splines parameters for components of the bar displacement. It is important to note that in relative values the bar position change of 0.01 m does not significantly influence the center of mass position. In Fig. 4 initial and smoothed values of the bar displacement components are given. Results of the smoothing procedure, taking into account the above-mentioned constraints, are presented in Fig. 5. Increase of the lower boundaries for smoothing parameters leads to displacement of the bar towards its neutral position. As one can see from Fig. 5 it yields paradox results: calculated wrist moment is more than the shoulder one. As a generalization we consider a synthesis of backward grand circles on the elastic bar with a following jump-off with performance of double-somersault in stretched out pose or four backward somersaults in grouped position for 8-element AM motion (see Fig. 6-7).

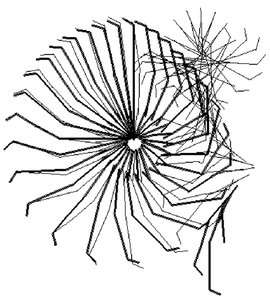

Fig. 6

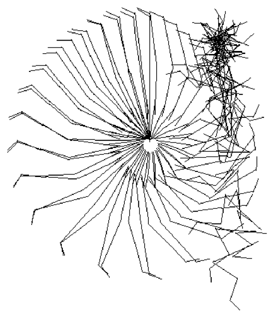

Fig. 7

The kinematic control in hip joint and shoulder joint angle were subjected to variation of relative angular velocities (Fig. 8). Inter-element moments charts are given in Fig. 9. One can see, in particular, that shoulder moment significantly increased during the second circle with respect to its value after the first circle and with respect to all other inter-element moments. This is due to the requirement of increase of relative angular velocity at the shoulder joint with respect to the first circle (see Fig. 8). At the moment of letting off the bar AM is slightly bent. Motion in the flying phase is determined by parameters of non-stationary items in constraint equations imposed for AM grouping and landing on the feet (see Fig. 6-7). Synthesis of considered motion was carried out as synthesis of one (support phase, flying phase, landing phase) complexly coordinated motion. In the synthesis process there were successively imposed (by groups) 23 constraint equations upon AM with 10 freedom degrees.

CONCLUSIONS: The suggested approach to iterative parametric adjustment of AM on the basis of employing constraint equations allows for exact matching of model motion characteristics with the most important experimental data. Less important data are estimated on average, which corresponds to traditional structural-parametric adjustment of AM.

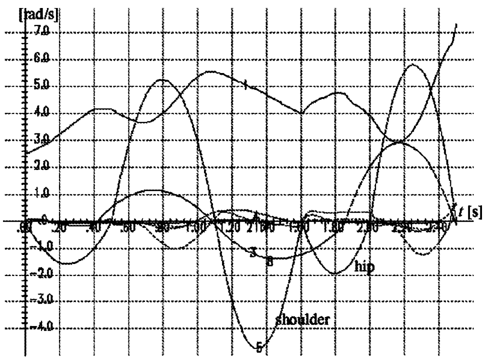

Fig. 8

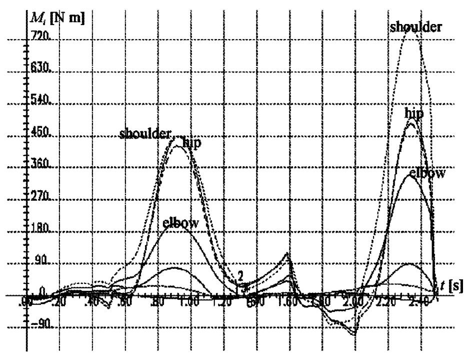

Fig. 9

REFERENCES:

Zinkovsky, A. V., Sholuha, V. A., Ivanov, A. A. (1997). Mathematical Modelling and Computer Simulation of Biomechanical Systems. *WSP*, Singapore, 216.