IOSUD - Universitatea Politehnica Timişoara
Şcoala Doctorală de Studii Inginereşti

ANALYTICAL STUDY OF HUMAN LOWER LIMB DYNAMICS IN GAIT
DOCTORAL THESIS

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ABSTRACT

The present thesis titled **Analytical study of human lower limb dynamics in gait** was elaborated in the framework of Doctoral School of Engineering - IOSUD Politechnica University of Timisoara. The thesis is structured on seven chapters from which six are consisting in development of the model and one underlines the conclusions and contributions. It contains 77 figures, 11 tables, 153 equations and 99 references, majority of recent publication date.

Chapter 1 is titled *Current research topics in biomechanics* and presents the research approach used by other authors in the field of biomechanics and especially regarding the instrumented motion analysis and dynamic models. The methods of investigation have been identified and studied in order to underline the main tools and techniques of each, in terms of similarities and differences. By identifying the shortcomings of the studied models, a new model can successfully be developed in the present thesis. The first chapter also establish the objectives of the thesis that will lead to achieving the new dynamic model of the lower limb.

Chapter 2 is titled *Computation of anthropometric parameters used in lower limb model* and presents the general concepts in anthropometry. The data and principles here presented were used in determining the anthropometric parameters for an investigated subject. The mass of a segment, the position of the center of mass in respect to the proximal and distal ends and also the radius of gyration was determined based on literature while the length and coordinates of the segment ends were determined experimentally by motion analysis.

The trajectories of the center of mass of the segments were graphically represented for walking on floor and on treadmill at low and high velocity. Also, the moment of inertia of the segments and the moment of inertia of the full limb were computed and represented, the variational character of the inertia being evidenced. Also, the total moment of inertia was correlated with the folding of the limb during swing phase of the gait and with the straitening of the limb in stance phases, everything in the context of reducing the biomechanical effort during the acceleration phases.

Chapter 3 is titled *Kinematic modeling of human lower limb* and presents a vectorial approach of the lower limb movement, modeled as 3 segments cylindrical joint mechanism. The simplification used is sustained by the natural behavior of gait, the

dominant movements being in the lateral plane while the movements in the other planes are low in values and only serves to limb adaptation to the various grounds.

The kinematical model takes into consideration the gai phases and the independent movement of each segment activated by the muscles. The model is based on three sub-models: two of each are designed like inverse pendulum (one with ankle fixed point - Strike and the other with forefoot fixed point – Propulsion) ant the third like a direct pendulum considering the hip joint fixed – Swing. The parameters were determined from the angular experimental data and using the designed analytical model in joints and center of mass of the segments.

The validation of the model was achieved by verifying the continuity at the limit of the parameters and comparing the results with numerical differentiation of the experimental data. The analytical model allows determining the linear velocity of the whole body by the difference between the experimentally obtained velocity in swing phase and the velocity obtained by analytic way. The graphical representations of velocities and accelerations for all considered phases evidences the variation of the kinematical parameters according to phase and orthogonal directions in lateral plane.

Chapter 4 is titled *Analytical Fourier transform of the segmental angles of the hip, thigh and foot* and presents the problematic of finding of the periodic analytical function for the limb movement.

Do to the cvasi-periodic character of gait, the Fourier transform was conducted on the segmental orientation angles in the purpose of finding the analytical function that can approximate the movement for the whole-time interval of the movement, and not only for one gait cycle. In the beginning the angular domains were divided into three periods, according to gait cycle. The angles were approximated on each interval by 3rd degree polynomial functions which were further used in developing the Fourier series.
The writing of the Fourier coefficients was done in generalized form, the equation obtained being useful for all studies that implies angles of different human segments. The Fourier solution approximates very well the experimental data, the degree of approximation being estimated by the computation of the RMS. It was observed that using four or five terms in Fourier series the approximation is really good.
The representation of the function in Matlab confirms by overlapping the fidelity between the experimental data and the analytical development, the equation being further applied in the dynamic model.

Chapter 5 is titled *Dynamic model of the lower limb* and presents the development of the analytical dynamical model in accordance to the gat phase (Strike, Propulsion and Swing) and for each individual segment by writing the momentum and angular momentum formulations for the identified movements. By writing the equilibrium equations for each segment, the reaction forces and toques at the hip, knee and ankle joints were determined. By solving the dynamic systems, the force components and torques were graphically represented for each time interval and for each joint. The dynamic parameters help in understanding the biomechanics of the lower limb without using the experimental invasive or harmful methods.
The continuity conditions at limit have been verified, the inflexion points of the forces and torques passing from one time interval to the next in a continuous manner. In addition, by summing the joint forces is overlapping well on the normal reaction force determined experimentally.

Chapter 6 is titled *The OHAM solution in solving the biodynamic multi-segment models* and presents the possibility of a reverse dynamic approach based on a differential equation founded in the literature, for a two segment biomechanic system. The purpose was to verify the utility of OHAM method in finding the approximate solutions of the nonlinear differential equations by providing the required parameters from the model proposed in this thesis.
In the first steps, by using three parameters of convergence and control for getting the approximate solution for angular displacements and angular velocities, solution that was compared with the numerical one. Then, in order to improve the approximation, an auxiliary function that has a supplementary convergence parameter was used.
The result of the approximation is a perfect match of both angular velocity and joint angle with the numerical solution and its derivative, the residuals of the improved solution being then times lower than for initial solution. So, the utility of OHAM was proved in solving the biodynamic equations, relying on the input parameters computed with the proposed model.

Chapter 7 is titled Conclusions and original contributions and presents the final part of the thesis, structured in three sub-chapters: general conclusions of the work, personal contributions and future developments and researches and mainly presents the conclusions that arise after elaborating and testing the model, highlighting the original parts and its utility. The future developments chapter opens new perspective both in