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This book of abstracts includes issues connected with the research and development of complex systems of various nature in conditions of uncertainty and multifactor risks, Grid and high performance computing in science and education, intelligent systems for decision-making, progressive information technologies for needs of science, industry, economy, and environment. The problems of sustainable development and global threats estimation, forecast and foresight in tasks of planning and strategic decision making are investigated.

В сборнике рассматриваются вопросы, связанные с разработкой и исследованием сложных систем разной природы в условиях неопределенности и многофакторных рисков, Grid и систем высокопроизводительных вычислений в науке и образовании, интеллектуальных систем поддержки принятия решений, прогрессивных информационных технологий для потребностей науки, промышленности, экономики, окружающей среды. Исследуются вопросы устойчивого развития и оценивания глобальных угроз, прогноза и предвидения в задачах планирования и принятия стратегических решений на уровне регионов, больших городов, предприятий.

У збірнику розглядаються питання, що пов'язані з розробкою та дослідженням складних систем різної природи в умовах невизначеності та багатофакторних ризиків, нових інформаційних технологій, Grid і систем високопродуктивних обчислень в науці і освіті, інтелектуальних систем підтримки прийняття рішень, прогресивних інформаційних технологій для потреб науки, промисловості, економіки та навколишнього середовища. Досліджуються питання сталого розвитку та оцінювання глобальних загроз, прогнозу та передбачення в задачах планування та прийняття стратегічних рішень на рівні регіонів, великих міст, підприємств.

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Calculation of dynamical characteristics of human gait with below-knee prosthesis

The perspective way of upgrading human lower extremities rehabilitation technologies is the development of effective methods for prosthetics results prognostication which are based on using the modern methods of mathematical design and computer science achievements. To achieve the rehabilitation effect it is necessary to perform the human gait characteristics of quantitative analysis, based on adequate mathematical models of human gait with prosthetic limbs and information of the experimental measuring.

The mathematical modeling problem of human gait with below-knee prosthesis over horizontal surface is investigated. The kinematic, dynamic and energetic characteristics of the gait, based on mathematical model of human locomotor apparatus and experimental data of human gait investigation, are determined. The experimental data of joint angles in hip, knee and ankle and reaction forces are obtained by biomechanical investigation in a sequence consisting of nearly 20 steps. The perturbations in experimental data are deleted by means of nonlinear digital filtration methods. The sequence of N steps reduced to double stride period and mean square domains (ε - tubes) of variations of joint angles and reaction forces have been built. The stiffness characteristics of ankle and metatarsal joints of the prosthesis device are also given from experimental investigation.

The human locomotor apparatus is modeled by system of 9-th rigid bodies. The model comprises trunk and two four-link legs (thigh, shank and two-link foot). The system moves due to interaction of gravity forces, walking surface reaction forces and control stimuli in the joints. We consider system's motion on double stride period $[0,\, T]$. The torques in prosthesis ankle and metatarsal joints $p(\gamma)$, $w(\varepsilon)$ generated by means of prosthesis structure elastic flexibility (γ, ε - angles in corresponding prosthesis joints).

Human gait is modeled over double stride period $t \in [0, T]$. We shall assume that there are the following five phases of the one leg action: rotation over the heel, support phase on both heel and metatarsal joint, motion on the phalanges, rotation over the ends of the toes and the swing phase of the foot over the surface. The time parameters for feet should satisfy the natural rhythmic conditions. The kinematic and dynamic restrictions of anthropomorphic contact for feet with walking surface, periodic conditions for system's movement (for angles and angle velocity), restrictions for relative positions of the feet on the initial t=0 and the end $t = T$ time and conditions of the dynamical torque balance in the ankle and metatarsal joints are imposed on model movement [3].

The motion's dynamic of the model in vertical (sagittal) plane is described by the system of 7-th nonlinear differential equations of 2-nd order and 4 kinetostatics balance conditions for inertia-free feet. In addition, the set of rhythmic, kinematic and dynamic restrictions and conditions of torque dynamical balance in prosthesis ankle and metatarsal joints are imposed [1–3].

The optimization approach based on energetic optimal principle of human locomotion is used for gait characteristics calculating. The human gait with below-knee prosthesis modeling problem is formulated as a nonlinear optimal control problem with restrictions imposed both on the phase coordinates and controlling stimuli and nondifferentiable (by Frechet) energetic functional.

Assume that we are given the single steps length L_i and the duration T_i, i=1, 2, the prosthesis stiffness characteristics $p(\gamma)$, $w(\varepsilon)$ and restrictions on the joint angles and surface acting forces. It is required to determine the mechanical system motion and controlling stimuli (torques on retained joints) over double support period $t \in [0, T]$, $T = T_1 + T_2$ that under given conditions minimizes the given objective energetic functional E. It should be noted, that in opposite to [3], the experimental

The study is part of an innovative scientific and technological project (client: National Academy of Sciences of Ukraine, contract № 1.1 on May 5, 2009) at affiliate support (experimental research of patient's gait and incoming data files generation) Ukrainian Research Institute for Prosthetics and Rehabilitation.

tensometric data of supporting surface reaction is taking into account.

The numerical algorithm for approximate solving of the formulated optimal control problem is developed. This algorithm is based on the converting the initial problem into nonlinear mathematical programming problem. We take into account the number of the degree of freedom for mechanical system and introduce a set of free variable functions (a part of generalized coordinates), that are parameterized by cubic smoothing splines. The values of these functions in the spline-approximation nodes are chosen as the optimization parameters. The restrictions on joint angles and supporting reactions are satisfied by external penalty functions. As the result, the original optimal control problem is reduced to the corresponding nonlinear mathematical programming problem. The real-coded genetics algorithms (RCGA) modification is developed for solving this problem. The key point of proposed RCGA modification is the use of consecutive order seven different crossover operators and four mutation operators, under which replacing parent chromosomes by offspring chromosomes is performing only when suitability of individuals increases.

The proposed algorithm for human gait with below-knee prosthesis mathematical modeling is implemented in the software package. Developed software package is intended for calculating kinematics, dynamics and energetic characteristics of the human gait with below-knee prosthesis for given values of the joint angles in the hip, knee and ankle, supporting reaction forces and the prosthesis stiffness characteristics. The proposed software package is a modern Windows application with multi document user interface, that developed by using Inprise Delphi 7 environment.

The software package input data are:

- the patient's locomotor apparatus linear and mass-inertia parameters;
- double stride length and duration;
- hip, knee, ankle joint angles;
- supporting reaction forces;
- prosthesis stiffness characteristic.

There is possibility during the mass-inertia parameters input to calculate ones accordingly to general accepted methodology from weight and height of the patient.

The output parameters of the software package are:

- the feet rhythmical phases duration over patient's double stride;
- the kinematical characteristics of the skeletal apparatus segments movement;
- torques in the preserved lower extremity hinges;
- double step energy costs;
- the point of the main vector support reactions moving.

The input and output data can be viewed in the table and graphical form. The abilities to adjust the parameters of visualization charts, graphs and tables and copy to clipboard are provided. All data (graphs, tables, arrays) can be printed in a form suitable for documentation. Effectiveness of the developed software is confirmed by solving a number of human gait dynamic applied problems.

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