NON-LINEAR ANALYSIS OF POSTUROGRAPHIC DATA

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Multidisciplinary experimental and theoretical study of human postural sway has been done in a series of cooperative projects by researchers from the Department of Biomechanics Vilnius Gediminas Technical University (Lithuania), Department of Theoretical and Applied Mechanics V.N. Karazin Kharkov National University (Ukraine) and Laboratory of Biomechanics M.I. Sytenko Institute of Spine and Joint Pathology (Ukraine) since 2006. A unique database on the sway parameters of normal convenient and some experimental stances has been gathered and analyzed. A mathematical model of the postural sway in the sagittal plane as an inverted n-link pendulum has been elaborated [1] and used for analysis of the two-leg and one-leg stances [2] of young healthy subjects. The oscillations of the centre of mass during the 30 s standing on two and one foot, as well as a step forward off the force platform with left/right legs have been studied (Fig.1). The number of links depends on the model. The 3-link model (trunk, thigh, shank) is the most popular one for the measurement data analysis [3]. When addition degrees of freedom (ankle, waist, neck) are considered, the 6–8 link models can be used for the more detailed data analysis. Since the n-link pendulums with n>1 exhibit chaotic dynamics [4] as well as 3D pendulum models, some of which were studied by L. Euler. Hip, shoulder and some other human joints are presented by spherical (elliptic) joints allowing rotations in 3D space, while the knee joint and some others allow the movement in 2D only. In our experiments the ankle, knee and hip joints of the healthy volunteers have been separately fixed in order to study the influence of each joint on the trajectory of the centre of mass (COM) of the body $y_{COM}(x_{COM})$. The curves $y_{COM}(x_{COM})$ have been computed on the digitized $x_{COM}(t)$ and $y_{COM}(t)$ time series.

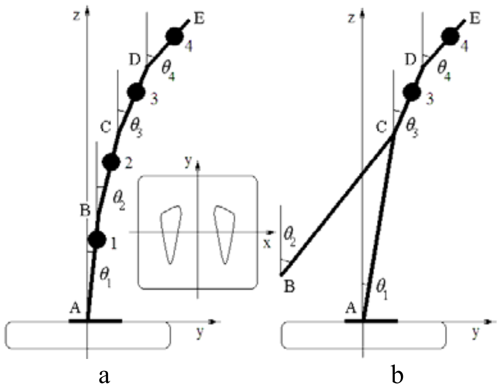

Fig.1. A 4-link inverted pendulum model for the two-leg (a) and one-leg (b) stances on the force platform.

Spectral analysis of the time series revealed three main harmonics for the studied postures. When a volunteer was balancing on one leg, all the harmonics were shifted towards the high frequencies and the sway amplitude in the sagittal plane was twice increased in comparison with usual quiet two-leg vertical stance. Decomposition of the sway trajectories into the rambling and trembling components revealed that in the course of the one-leg stance the balance control strategy includes 'scanning' of the larger area with bigger sway amplitudes in the vicinity of the stable state as compared to two-leg stance [2]. One-leg stance was suggested as an excellent tool to reveal the balance disorders. Additional diagnostic information can be obtained from accelerometty [5], different stances [6] and the developed method of indirect estimation of the functional state of human skeletal-muscular system [7].

The discrete short-time Fourier transform (DSTFT) has been applied to the time series g_n

$$G(m,f)=\sum_{-\infty}^{+\infty} g_n W_{n-m}\exp(-i\omega n)$$

where m corresponds to the time shift, $W[n-m]$ is the discrete windows function allows simultaneous analysis of the amplitudes G or power spectral density (PSD) in the frequency and time domains. The Gaussian function was chosen as $W[n-m]$.

The discrete wavelet transform (DWT)

$$\Psi(\tau,s)=\frac{1}{\sqrt{|s|}}\sum_{-\infty}^{+\infty} g_n\psi_k$$

where $k=(n-m)/s$, s is the scale, ψ_s is the wavelet function, has been applied to the same time series g_n.

The PSD distributions in the frequency and time domains of the $x_{COM}(t)$ and $y_{COM}(t)$ time series are presented in Fig.2a,b, while the corresponding DWT distributions in time and scale are given in Fig.3a,b. It is shown, the body oscillations during the 30 sec test experienced periodical variations in the frequencies in the frontal plane (Fig.2a), while the spectrum was quite stable in the sagittal plane (Fig 2b). Similar regularities have been found in other volunteers. The self-similar behavior of the two-leg sway also exhibited some periodicity in the time domain; 4/3 cycles in the main low-frequency harmonics in the frontal/sagittal planes are presented in Fig.2 c/d accordingly. The periods have been associated with beginning of the test when a person is accommodating to the test conditions; the intermediate part, and the final part when the body becomes already tired because of keeping the stable position.

The mathematical model of the inverted multi-link pendulum has been studied. Oscillations of the links are governed by the Lagrange equations. Mass and inertia of each link, as well as the reaction and friction forces in joints are taken into consideration. Kinetic and potential energy have been computed for each segment and substituted in the Lagrange equations. Supposing the small variations of the angles θ_{1-4} and setting that $\sin(\theta_j)\sim\theta_j$, $\cos(\theta_j)\sim 1$ and neglecting the terms

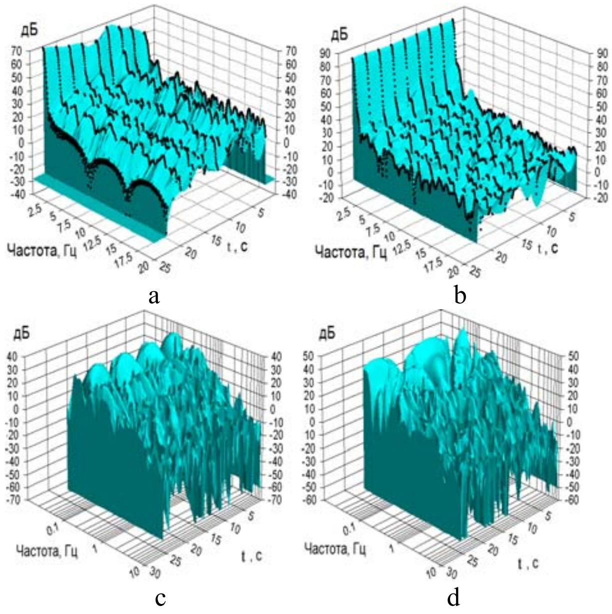

Fig.2. DSTFT/ DWT distributions of the $x_{COM}(t)$ (a/c) and $y_{COM}(t)$ (b/d) curves of the two-leg stance of a healthy individual.

$\sim(\theta_j)^2$ one can obtain the quasi-linear system of ODE governing oscillations of the segments in the form

$$M \cdot \frac{d^2}{dt^2}\vec{\theta} + K\left(\frac{d}{dt}\vec{\theta}, \vec{\theta}\right) + N \cdot \vec{\theta} = \bar{u}\left(\frac{d}{dt}\vec{\theta}, \vec{\theta}\right) \qquad (1)$$

where $\vec{\theta}^T = (\theta_1, \theta_2, \theta_3, \theta_4)$, T is transposition sign, M is the mass-inertia matrix, K is centrifugal matrix, N is gravity matrix, $\bar{u}$ is the control function which is usually supposed to be proportional to deviations of angles and velocities. Components of the matrices M, K, N are long complex expressions which are not presented here for brevity. The quasi-linear system (1) has been solved numerically. Amplitudes and frequencies of body oscillations have been computed, analyzed and compared to the measured data.

It was sown the COM trajectories during the two-leg and one-leg stances, as well as at the step forward off the force platform by the left/right leg contain important information for differential clinical diagnostics of the spine and joint pathologies.

LITERATURE

1. Karpinski M.Yu., Kizilova N.N. Automated registration and analysis of the posturopgaphic data based on the mathematical model of human body as multi-link system. // Appl. Radioelectr. – 2007. – v.6,N1. – P.10–18.
2. Karpinsky M.Yu., Kizilova N.N. Computerized posturography for data analysis and mathematical modelling of postural sway during different two-legged and one-legged human stance. // J.Vibroeng. – 2007. – v.9,N3. – P.118–124.
3. Classics in Movement Sciences. / M.L. Latash, V.M. Zatsiorsky (eds). Human Kinetics, USA. – 2001. – 452p.
4. Arnold V.I., Kozlov V.V., Neishtadt A.I. Dynamical Systems III, Springer, 1988.
5. Griskevicius J., Jarmaliene E., Sesok A., Daunoraviciene K., Kizilova N. Evaluation of human postural balance in quiet standing by direct measurement of human body center of mass acceleration. // J. Vibroeng. – 2009. – v.11,N3. – P.556–561.
6. Kizilova N., Karpinsky M., Griskevicius J., Daunoraviciene K. Posturographic study of the human body vibrations for clinical diagnostics of the spine and joint pathology. // Mechanika. – 2009. – N6(80). – P.37–41.
7. Karpinski M.Yu., Karpinska O.D., Kizilova N.N. et al A method of indirect estimation of the functional state of human locomotory system // Patent on useful model U200907801. UkrPatent N46957, 11.01. 2010. Bulletin N1/2010.

FLOW–WALL INTERACTION IN THE ANEURYSM MODEL

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The aneurysm occurs when part of a blood vessel inflates abnormally due to damage or weakness in its wall. As the wall is weakened, it balloons out under the action of transmural pressure at its weakest point creating a saccular or fusiform bulge called aneurysm. As the aneurysm grows, the deformation and the displacement of the wall become large, the stress increases which leads to the rupture of wall of the aneurysm. The aneurysm is likely to form as a result of a biological processes caused by biochemical or structural inherited defects, infection disease and specific hemodynamic factor [1]. The fact that the aneurysm often occurs at a specific location in arteries and veins, characterized by unique hemodynamic conditions, strongly suggests that the hemodynamic plays an important role in the formation and in the development of the aneurysm [2].

Several nonlinear mathematical models describing the long term evolution of the aneurysm have been developed in the literature, in those models, the replacement rate of elastin fibers by collagen fibers is supposed to be dependent on hemodynamic conditions. As the time scale of the dynamic considered by these models, which is of the order of several years, is very large in comparison of the heart cycle, which is of the order of one second, the hemodynamic conditions (pressure and stress) are found by solving Navier–Stokes equations in a fixed domain. The fixed domain is updated every once in a while to take account to the evolution of the geometry of the aneurysm. Therefore, they implicitly supposed that the movement of the wall does not affect the flow. The present work is mainly concerned by the action of the movement of the wall on the flow and vice versa, therefore, a full interaction between the flow and the wall is considered. The aim of the simulation is to predict the tension in the elastic moving wall of the aneurysm for inferring its rupture