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MEASUREMENT AND COMPENSATION OF MECHANICAL VIBRATIONS IN ARTICULATIONS OF ELECTROMECHANICAL BIPED ROBOT

The objective of our work is to present the measurement and the compensation algorithm of vibrations in a knee articulation of a biped robot. Our approach is based on the modified Ren-Lewis-Zhang compensation method.

Introduction. The influence of rhythmical perturbations on the tracking precision of articulation trajectory during the walking of an electromechanical robot is significant. A main reason is mechanical vibrations that appear due to the finite rigidity and flexibilities of structure, mechanical backlash in transmission and load/idle cycles against ground. This provides tracking errors up to 2-5 degrees at the output of an articulation. For a two legged walking robot these phenomenon is critical and can cause the fall of the robot. Values of errors and their origin, which were discovered in our preliminary experiments [1] on our biped robot, are well coherent with researches of other authors [2, 3]. These authors pointed out connection between actuating motor and output of articulation as viscous-elastic due to deformations in Harmonic Drive reducer, and mechanical backlash. They showed the necessity to reduce caused oscillations [3].

Rhythmic modes can be distinguished by their frequency in relation with the bandpass Ω_B of a system: 0,01-0,1 Ω_B – low ; 0,1-0,8 Ω_B – middle, 0,8 Ω_B and more – high; and by the mechanical origin of their appearance: external oscillations due to the external application of force or torque (when the foot touches the ground), and internal due to the flexibility, deformations and backlash. In this work we consider low and middle frequency oscillations which have internal and external origin. High frequency can be considered as a noise and not studied.

To compensate mechanical vibrations, one of possible solutions consists in forming special articular trajectories of walking with limitation of acceleration and jerk, but this approach limits walking speed. Stabilization of vibrations if widely used in machine tools, for chatter suppression [4], but constraints to stabilize the system are different. In our case, the robot legs needs to follow a complex trajectory in periodic and discontinuous interaction to the ground, whereas in machine tool the using tool is always in contact to the matter. We found interesting the work of X. Ren,, F. Lewis and J. Zhang [5] where they propose an adaptation of a system to the changing conditions (frequency, amplitude). Nevertheless, the method is difficult to realize for multiple d.d.l. like in biped robot, so we propose some modifications.

Method and materials of research. It is usually hard to measure the articulation output angle and to subtract oscillations. Some authors use encoder [3], but due to mechanical design particularities, it is not the best solution because of necessity to calculate the derivate of a signal. It is much more efficient to calculate the angular acceleration using accelerometer. To evaluate our oscillations measurement, we tested it using a simple compensation principle on a knee of a biped robot. The transmission includes a Harmonic Drive reducer 1:125 and a belt 1:2. The frequency of relaxation oscillations is 10 Hz.

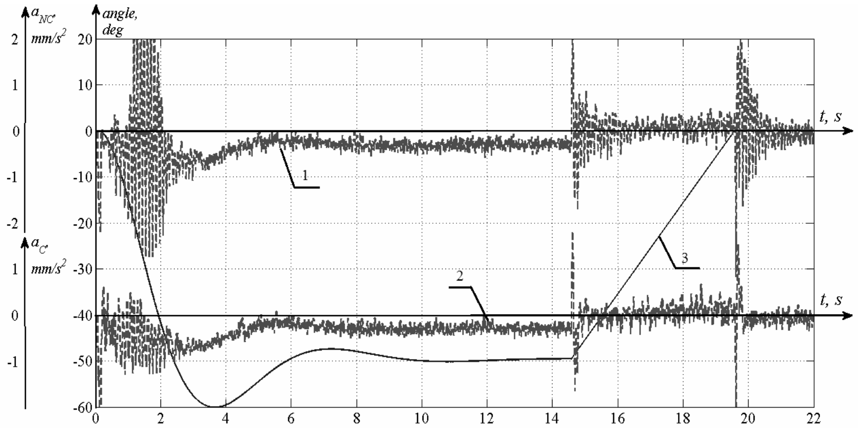

Figure 1 – Cycle of movement : 1 – articulation vibrations without compensation, 2 - with compensation, 3 – target signal

Measurement of angular vibrations is done with two MEMS sensors (inclination meter SCA 121T-D05 and accelerometer ADXL 150-EM3) placed at the extremity of the leg, one over the other. Their output signals are conditioned with specially developed electronic card, which makes analog subtraction of sensor offset voltage and amplification of his output signal with precision more than 0.1 %. The resulting signals are digitized by the robot industrial unit controller with 10 kHz sampling frequency and 14 bit resolution.

To calculate angular acceleration, additional treatment is needed. The accelerometer output (three projections of acceleration a_x, a_y and a_z) contains the gravity acceleration component (g_z, g_y, g_z) and acceleration due to the movement (e_x, e_y, e_z). First, the accelerometer data is transformed from Cartesian system of coordinates (x, y, z) to the spherical system |A|, θ, φ. The inclination signals α, β are than subtracted from values θ and φ to receive the angular acceleration. Before subtracting, inclination signals are filtered on-line with moving average filter (window width 0,1s), eliminating acceleration component in inclination meter signal. To achieve fast realization of sensors signal treatment, functions *sin*, *cos*, *tanh* were tabbed with 200 points. The linear interpolation for intermediate points is then used. The resulting algorithm turns in real time on the industrial unit controller with sampling rate 0.5 µs.

The successful reduction of oscillations (fig. 1) using simple inversion of vibration signal added to the control system input approves the capacity of proposed method to be implanted in the compensation schemes.

Learning compensation with neural networks. The received signals are then used in a compensation neuronal network feedback-feedforward method (fig. 2). The original structural scheme and neuronal network parameter adaptation law, based on Lyapounov criteria, are described in [5]. We have changed the two-loop scheme by classical three-loop current-velocity-position control and changed the application point of the output of neuronal network to the input of system. Thus, the input must contain inverse transfer function of a control system, which can be approximated by $(1/K_p) / (1+T\text{p})$. Here K_p is a resulting gain of motor positioning system, and T is an equivalent time constant.

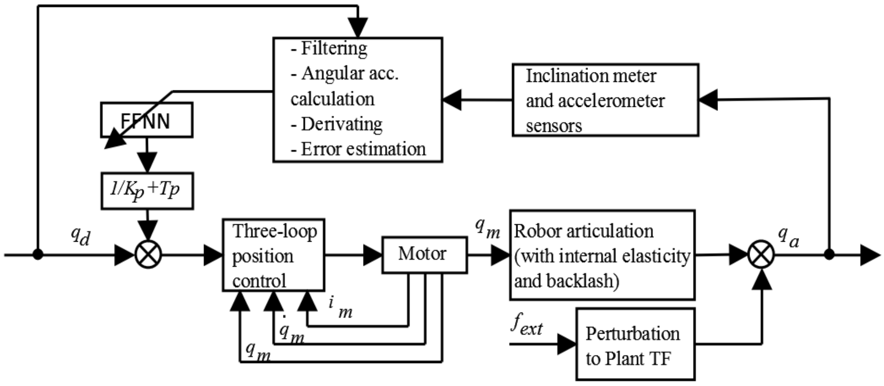

Figure 2 – Modified structural scheme of a control system

This scheme must be tested to ensure its ability to compensate disturbances with frequencies form 3 Hz to 100 Hz, intrinsic to humanoid robots. For instance, we engage in experimental implementation of the presented method.

Conclusions

1. The experimental results with successful compensation of vibrations in one d.d.l. show the correct measurement approach of oscillations coming from imperfections of mechanical conception in humanoid robot articulations: elastic deformations inside of Harmonic Drive reducers, mechanical backlash and flexibility of construction.
2. The proposed modifications to the structure [4] permit to simplify the practical application of the compensation algorithm. Thus, implementation can be divided in two independent phases: parameterization of classical three-loop circuit (current-velocity-position) for an electric motor and adjustment of a neuronal network feed-back compensator.

Perspectives

We envisage continuing the experimental study of the vibration compensation algorithm for the six d.d.l. of each leg of our biped robot ROBIAN [5]: his hip, knee and ankle articulations.

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