Motion Design of Two-Legged Locomotion Process of a Man

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Abstract. The geometric construction of bio-kinetic apparatus of man's locomotion representation in cybernetic form is actual task. It is very important for motion design and locomotion coordination (control) tasks solving. For this aim the hierarchical multilevel systems construction was chosen and applied in this paper for bio-kinetic apparatus of man description. The hierarchical multilevel systems coordination method realisation in geometric design of man's locomotion is also presented in the paper.

1 Geometric Representation of Bio-kinetic Apparatus Construction

Geometrical construction of men in our case is regarded as a set of bio-kinetic chains and limbs. It can be presented as hierarchical multilevel system by Mesarovi and Takahara [1] in form of *aed* [3-6] (*aed* is an ancient Greek word):

$${}_gS^\ell = \{\omega^\ell, S_0^\ell, \sigma^\ell\} \quad (1)$$

where:

ω^ℓ - aggregated dynamic realisation (model), which represents the construction (body and bio-kinetic chain) of men as the unit in its environment;

σ^ℓ - geometric construction of a bio-kinetic apparatus;

S_0^ℓ - coordinator, which connects σ with ω and in this way, coordinates the locomotion process.

ℓ - index of level.

ω^ℓ is described with the help of dynamic systems $(\bar{\rho}, \bar{\varphi})$ [2]:

$$\begin{aligned} \bar{\rho}^\ell &= \{\rho_t : C_t \times X_t \rightarrow Y_t \text{ \& } t \in T\}^\ell, \\ \bar{\varphi}^\ell &= \{\varphi_{tt'} : C_t \times X_{tt'} \rightarrow C_{t'} \text{ \& } t, t' \in T \text{ \& } t' > t\}^\ell, \end{aligned} \quad (2)$$

where C – states, X – inputs, Y – outputs, ρ - reaction, φ - states transition function, T –time of level ℓ .

ω^ℓ in general case includes the aggregated dynamical realisations of object ${}_o S^\ell$, its environment ${}_e S^\ell$, actions ${}_o P^\ell$ of ${}_o S^\ell$ in ${}_o S^\ell$ and actions ${}_o P^\ell$ of ${}_o S^\ell$ with ${}_o S^\ell$. Structure σ^ℓ is defined as:

$$\sigma^\ell = \{S_0^\ell, \{\bar{\omega}^{\ell-1}, {}_\sigma U^\ell\}\}, \quad (3)$$

and contains aggregated representations $\bar{\omega}^{\ell-1}$ of lower level elements (body, thigh, shank, foot, fingers) and their connections ${}_\sigma U^\ell$ – the joints.

For example, the common part of the thigh $\omega_1^{\ell-1}$ and the shank $\omega_2^{\ell-1}$ is their structural connection – the knee ${}_\sigma U_{1,2}^\ell$.

Coordinator is also presented in this case in form of *aed*:

$$S_0^\ell = \{\omega_0^\ell, S_{00}^\ell, \sigma_0^\ell\}, \quad (4)$$

and coordinates the locomotion process on its layers of choice, learning and self-organisation. All metrical characteristics of bio-kinetic apparatus (relational angles, length of limbs etc.) are described by numeric positional systems – numerical characteristics.

2 Coordination Method Realization in Design of Men's Locomotion

Geometric design process (motion design) of two-legged locomotion of man contains two stages and executed by coordinator [11]:

- Synthesis (creation) of geometric construction of bio-kinetic men's apparatus;
- Motion design and evaluation of kinds (states) of men locomotion (walk, run and others).

On the first stage coordinator S_0^ℓ realise (on its choice layer) the synthesis of geometric elements $\bar{\omega}^{\ell-1}$ of bio-kinetic apparatus and after that connects the elements by their structural common parts ${}_\sigma U^\ell$ – joints. In this way the synthesis process of structure of whole bio-kinetic apparatus of man is realised. This process may be described as follows:

$$S_0^\ell : \{\bar{\omega}^{\ell-1}, {}_\sigma U^\ell\} \rightarrow \sigma^\ell. \quad (5)$$

The structure $\bar{\sigma}^{\ell-1}$ of elements $\bar{\omega}^{\ell-1}$ (for ins. shank) is constructed in computer from geometrical objects $\bar{\omega}^{\ell-2}$ (conditional points) – cubes (Fig.1).

Fig. 1. The example of geometric structures $\bar{\sigma}^{\ell-1}$ synthesis of elements $\bar{\omega}^{\ell-1}$ (for ins. shank)

Fig. 2. The structure of the one part (one leg) of bio-kinetic apparatus of a man

Conditional points $\bar{\omega}^{\ell-2}$ connected by its sides ${}_\sigma U^{\ell-1}$. The number of elements n and its sizes w defines the width w and length l of whole geometrical structure of the object. The higher level structure σ^ℓ is constructed from $\bar{\omega}^{\ell-1}$

elements with taking into account the interactions ${}_{\omega}U_1^{\ell}$ with the environment ${}_{\omega}S_i^{\ell}$ (Fig.2).

To solve the task of *second stage* (motion design), man is presented in accordance with hierarchical multilevel systems representation as the object ${}_oS^{\ell}$. The locomotion process of man ${}_oP^{\ell}$ in its environment ${}_{\omega}S^{\ell}$, the environment, which actively affects on the men through its process ${}_{\omega}P^{\ell}$ and this process are also regarded.

Men's environment can be heterogeneous in general case, for instance it is possible to have an obstacles on the trajectory of motion. That is why, coordinator realises its several coordination strategies while walking – from the strategy of *full determination* (the trajectory is known, the external state (state of the environment) is also known) to the coordination strategy of *full information uncertainty* – the trajectory is uncertain (motion in unknown environment); the absence of the possibility to receive the information about the state (structure) of both the path and environment. For instance, in case of man locomotion in conditions of full darkness.

The motion ${}_oP^{\ell}$ of man ${}_oS^{\ell}$ in its environment ${}_{\omega}S^{\ell}$ is called the change of man's interconnections ${}_{\omega}U^{\ell}$ with elements S_i^{ℓ} ($i \in I^{\ell+1}$) of environment system ${}_{\omega}S^{\ell}$ (Table 1). The contact state ${}_{\omega}U_1^{\ell}$ of man's stand (base) leg with path surface and the state ${}_{\omega}U_2^{\ell}$ of geometric form of bio-kinetic apparatus (Fig.3) (both base and swing legs) we will regard as man's interconnections with its environment while walking:

$${}_{\omega}U^{\ell} = \{ {}_{\omega}U_1^{\ell}, {}_{\omega}U_2^{\ell} \} \quad (6)$$

Table 1. Various states of ${}_{\omega}S^{\ell}$, ${}_{\omega}U_1^{\ell}$ and ${}_oS^{\ell}$

Systems	C (states)			
${}_{\omega}S^{\ell}$ (way)	Hard	Snow	Hard + Water	Send
${}_{\omega}U_1^{\ell}$ (foot)	Heel	Foot	Toe	Foot + toe
${}_oS^{\ell}$ (men)	Different geometrical parameters of bio-kinetic apparatus of men			

Interactions ${}_{\omega}U^{\ell}$ are changeable in time and differ for various kinds (types) of motions: for instance for walking faze the ${}_{\omega}U_1^{\ell}$ can't be equal to zero on whole period of walking time, but for running faze there are moments of time when ${}_{\omega}U_1^{\ell} = 0$.

There are deformations in bio-kinetic apparatus which cause (during locomotion process) the coordinated movements of its parts – hands and legs: flexion, straightening, inclination (bending), swing. The change of the connections ${}_{\sigma}U^{\ell}$ of above mentioned elements, which are the parts of bio-kinetic apparatus structure σ^{ℓ} we will recognise as deformations. The coordinator task in motion design is to provide the cohered motion of bio-kinetic apparatus and deformations of its elements, i.e. ${}_{\sigma}U^{\ell}$.

Fig. 3. One state of bio-kinetic apparatus geometric construction in locomotion process (obtained from computer monitor)

Structural connections in geometrical sense are the angles between parts of bio-kinetic apparatus (fingers, foot, led). So, coordinator task is to change continuously these angles to provide the locomotion process. Formally, the task solving is presented in following form:

- for coordinator (as its reaction): $\rho_0^{\ell} : C_0^{\ell} \times \sigma_t^{\ell} \rightarrow \sigma_{t'}^{\ell} \& \sigma_{t'}^{\ell} = Y_0, \sigma_t^{\ell} = X_0$, (7)
- for system (as state transition): $\varphi_{tt'}^{\ell} : \sigma_t^{\ell} \times {}_{\sigma}U_{tt'}^{\ell} \rightarrow \sigma_{t'}^{\ell}$,

where σ_t^{ℓ} and $\sigma_{t'}^{\ell}$ are the state of bio-kinetic apparatus structure at moments of time t and t' correspondingly, $t' > t$; ${}_{\sigma}U_{tt'}^{\ell}$ is the change of angles during the period of time tt' , is the state of bio-kinetic apparatus structure at moment of time t' and $t' > t$. The dependence of the angle changing in locomotion process is reflected in [7].

In this case we deal with the biomechanical type of motion for which the next dependence is true:

$${}_{\omega}U^{\ell} \Big|_{\overline{T}_{tt'}^{\ell}} = const \quad . \quad (8)$$

In other words, the external connections ${}_{\omega}U^{\ell}$ of regarded apparatus depend only on the change of its structural connections ${}_{\sigma}U^{\ell}|\overline{T}_{tt'}^{\ell}$ during the period of time $\overline{T}_{tt'}^{\ell}$.

It is possible to present the motion measures (velocity and others) as the change measures of dynamic systems states in elementary time ${}_{\tau}\eta_T^{\ell}$ in metrical M^{ℓ} , structural Ξ^{ℓ} and boundary Δ^{ℓ} (geometric forms) spaces. The motion measures have their directions in dependence of the element address in the environment, in accordance with which the present process is regarded.

3 Conclusion

In comparison with known methods [8-10] the proposed coordination one describes the bio-kinetic apparatus of man as hierarchical multilevel system, that allows to solve the design task of man locomotion as interconnections coordination of cohered structural and dynamical representation of apparatus.

In known methods the general rotation angles of limbs (as kinematical mechanism) in 3-D space are calculated. In proposed one we regard the relative angles between limbs as their interconnections only. It allows reduce the number of calculations.

During the motion design processes the dependence of functional parameters (kinds of motions) from structural ones (sizes, angles etc.) of bio-kinetic apparatus elements while walking was established (determined).

Computer program is written on Pascal and implemented on the simplest PC what allows to solve the task fast with minimal computer memory and speed.

References

1. Mesarovic, M.D., D.Macko, D., Takahara, Y.: Theory of Hierarchical Multilevel Systems Academic Press, New York and London (1970).
2. Mesarovic, M.D., Takahara, Y.: General Systems Theory: Mathematical Foundations, Academic Press, New York and London (1975).
3. Novikava, S., Miatliuk, K., et al.: Aed Technology for Ecological, Social and Engineering Systems Coordination. Proc. of 8th Int. Symposium on Modular Information Computer Systems and Networks, Dubna, Russia (1991) 145-152.
4. Novikava, S., Miatliuk, K., et al.: Hierarchical Multilevel Systems in Aed realization. Proc. of 9th Int. Conf. on Mathematical and Computer Modeling, Berkeley, USA (1993) 71.
5. Novikava, S., Miatliuk, K., Gancharova, S., Kaliada, W.: Aed Construction and Technology in Design. Proceedings of 7th IFAC/IFORS/IMACS Symposium on Large Scale Systems, LSS'95, Pergamon Press, London (1995) 379-381.
6. Novikava, S., Miatliuk, K., et al.: Aed Theory in Hierarchical Knowledge Networks. In: Journal of Studies in Informatics and Control 6(1) (1997) 75-85.
7. Jaworek, K.: Indices method of assessment human gait and run. Pub. IBIB-PAN, Warsaw, Poland, (1992). (in Polish)

8. Jaworek, K.: About the index of movement of terrestrial mammals. Proc. of the Biomechanics'2003. Int. Conference. Ed. By Acta of Bioengineering and Biomechanics 5 S1 (2003) 199-205.
9. Pennycuick, C.J.: Newton rules biology. A physical approach to biological problems. Pergamon Press, Glasgow (1992).
10. Vaughan, C.L.: Theories of bipedal walking: an Odyssey. Journal of Biomechanics 36 (2003) 513-523.
11. Jaworek, K., Miatliuk, K.: Coordination method in geometric design of two-legged human gait. Proc. of the Men's Locomotion Conf., Gdansk, Poland (2003) 20. (In Polish)