Conceptual Model for Design of Human-Exoskeleton Biomechatronic System

Kanstantsin MIATLIUK and Franciszek SIEMIENIAKO
Department of Automation and Robotics, Bialystok University of Technology,
Bialystok, Poland, k.miatliuk{frank}@pb.edu.pl

Keywords: Hierarchical systems, conceptual model, biomechatronics, exoskeleton, design.

Abstract

The paper suggests a conceptual model for systems design in biomechatronics based on the ideas of mathematics&cybernetics originated by systems theory. Traditional mathematical models and models of artificial intelligence do not allow describing biomechatronic systems being designed on all its levels in one common formal basis, i.e. they do not give connected descriptions of the systems structure, the system as dynamic unit in its environment and the environment construction. So, the models of hierarchical and dynamic systems were chosen as a theoretical means for design&control tasks solving in biomechatronics. Theoretical construction of the conceptual model proposed in form of *aed* (standard block of hierarchical systems) is considered. The example of the model application in the description of Human-Exoskeleton system taking into account its biomechatronic subsystems is presented after that.

1. INTRODUCTION

To coordinate (design&control) human-exoskeleton biomechatronic system it is necessary to take into account several levels of this system:
structure of system being designed (lower level), its aggregated dynamic representation as a unit in system environment (current level) and the environment construction and technology (higher level).

Besides, in comparison with other engineering systems in design process of mechatronic subsystems we deal with objects which contain connected mechanical, electromechanical, electronic and informational parts. We also have to take into account man-machine interactions of social and mechatronic objects as subsystems of general engineering level. All of these objects are of different nature. No one of various methods and models of mathematics and artificial intelligence used for each system coordination which can describe all mechatronic subsystems with all their specific characteristic features and at the same time describe the mechanism of their interaction in the structure of higher level system and the system as a unit in its environment. It is very important to determine the common informational means for design&control tasks which will describe biomechatronic subsystems of human-exoskeleton in common formal basis. This task is especially topical for the systems of computer aided design CAD and usually performed on the stage of conceptual design (CD) of general lifecycle of biomechatronic system.

Informational model must also allow solving design tasks under condition of any information uncertainty:

to create and change the system construction & technology by selecting units of lower levels and settling their interactions to make the state and activity of the system in higher levels (environment) best coordinated with their aims (the uniting&selecting stratum);

to change the strategies and ways of design task solving when uncertainty is removed and new knowledge is created (learning and selfcoordination strata).

To solve the design task symbol construction and technology of Hierarchical System [1-4] with its standard block *aed* [4] (ancient Hellenic word) was chosen as the conceptual model.

2. CONCEPTUAL MODEL

BioMechatronic system S^{ℓ} being coordinated (designed & controlled) is expressed in frames of *aed* model by the next formal system:

$$S^{\ell} \leftrightarrow \{\omega, S_0, \sigma\}^{\ell} \; , \qquad (1)$$

where ω^{ℓ} is aggregated dynamic realization of system S^{ℓ}, σ^{ℓ} is structure of S^{ℓ}, S_0^{ℓ} is coordinator, ℓ is index of level. ω^{ℓ} is presented in form of dynamic system [1,3].

Aggregated dynamic representations ω^{ℓ} of all *aed* elements are presented in form of dynamic system $(\overline{\rho}, \overline{\varphi})^{\ell}$:

$$\overline{\rho}^{\ell} = \{\rho_t : C_t \times X_t \to Y_t \;\&\; t \in T\}^{\ell} , \qquad (2)$$
$$\overline{\varphi}^{\ell} = \{\varphi_{tt'} : C_t \times X_{tt'} \to C_{t'} \;\&\; t, t' \in T \;\&\; t' > t\}^{\ell} ,$$

where C^{ℓ} is state, X^{ℓ} is input, Y^{ℓ} is output, T^{ℓ} is the time of level ℓ, $\overline{\rho}^{\ell}$ and $\overline{\varphi}^{\ell}$ are reactions and state transition functions respectively.

ω^{ℓ} and σ^{ℓ} are connected by coordinator and include the dynamical realizations and structures of object ${}_{o}S^{\ell}$, its environment ${}_{\varepsilon}S^{\ell}$, processes ${}_{o\pi}S^{\ell}$ of object ${}_{o}S^{\ell}$ in environment ${}_{\varepsilon}S^{\ell}$ and actions ${}_{\pi\varepsilon}S^{\ell}$ of environment ${}_{\varepsilon}S^{\ell}$ with object ${}_{o}S^{\ell}$.

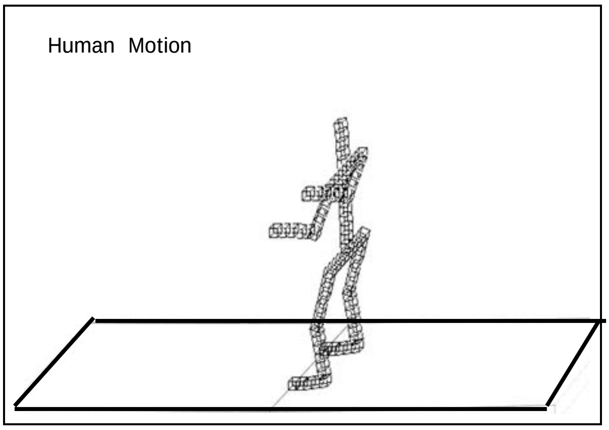

Fig. 1 One state of human being in motion obtained from computer monitor.

The structure includes aggregated dynamical realizations of lower level elements and their structural connections. The main design and control tasks are solved by coordinator on its selection, learning and self-organization strata. Coordinator has its own dynamic realization ω_0^ℓ, structure σ_0^ℓ, S_{00}^ℓ control element and realizes interlevel connections. Availability of control element allows evaluation and change of coordinator by itself.

Aed model also meets the general requirements of design and control systems [3-11]. Numeric and geometric characteristics of systems being designed are presented in *aed* informational basis [3-6].

3. DESCRIPTION OF HUMAN-EXOSKELETON

In the paper the conceptual models of the mechanical, human (biomechanical) and informational (computer) sub-systems of biomechatronic object under consideration (human-exoskeleton system) are presented in *aed* basis of hierarchical systems. Biomechanical subsystem is regarded for the case of human motion (Fig.1). Mechanical part is given in form of the conceptual presentation of the exoskeleton lower extremity (leg) and its CAD virtual model (Fig.2) [12]. Design (CAD) subsystem which creates the exoskeleton virtual model is described as the computer (informational) part of the human-exoskeleton biomechatronic system. Conceptual model of the program system for human motion simulation is also presented as the description of the computer sub-system.

The examples of computer realizations of the design tasks in frames of Delphi (Fig.1), SolidWorks (Fig.2), and MatLab program systems are also given in the paper.

Aed informational model was applied in the other tasks for the description of mechatronic systems [9-11], modeling of the assembling process [5], human motion design [6-8].

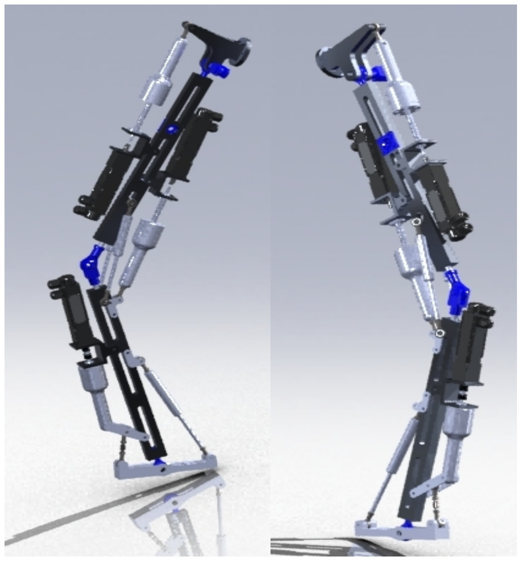

Fig. 2 Virtual model of lower extremity of exoskeleton.

References

[1] M. Mesarovič and Y. Takahara, Abstract Systems Theory, Springer Verlag, 1990.

[2] M. Mesarovič, D. Macko and Y. Takahara, Theory of Hierarchical Multilevel Systems, Academic Press, 1970.

[3] S. Novikava and K. Miatliuk, Hierarchical System of Natural Grammars and Process of Innovations Exchange in Polylingual Fields, *Kybernetes*, Emerald, Vol. 36, No.5/6, 2007, pp.736-748.

[4] S. Novikava, K. Mialtiuk, S. Gancharova, W. Kaliada, *Aed* construction and technology in design, Proc. 7th IFAC Symp. on LSS, Pergamon, 1995, pp. 379-381.

[5] K. Mialiuk, Z. Gosiewski, F. Siemieniako: Coordination Technology in the Assembly Operations Design, Proc. IEEE SICE-ICASE Int. Joint Conf., Korea, 2006, pp.2243-2246, available at http://ieeexplore.ieee.org/.

[6] K. Miatliuk, S. Novikava , K. Jaworek, Motion design of two-legged locomotion process of man, LNCS 3039, Springer-Verlag 2004, pp. 1103-1109.

[7] K. Miatliuk, Y.H. Kim, K. Kim, Motion Control Based on the Coordination Method of Hierarchical Systems, *J. of Vibroengineering*, Vol. 11, No. 3, 2009, pp.523-529.

[8] K. Miatliuk, Y.H. Kim, K. Kim, Human Motion Design in Hierarchical Space, *Kybernetes*, Emerald, Vol. 38, No. 9, 2009, pp.1532-1540.

[9] K. Miatluk, F. Siemieniako, Theoretical Basis of Coordination Technology for Systems Design in Robotics, 11th IEEE Int. Conf. Methods and Models in Automation and Robotics, Poland, 2005, pp.1165-1170.

[10] K. Miatliuk, Y.H. Kim, F. Siemieniako, Informational Basis for Mechatronic Systems Design, Asian Int. Symp. on Mechatronics AISM2008, Sapporo, Japan, 2008, pp. 538-543.

[11] K. Miatliuk, Y.H. Kim, K. Kim, F. Siemieniako: Use of Hierarchical System Technology in Mechatronic Design, *Mechatronics*, Elsevier, Vol. 20, 2, 2010, pp. 335-339

[12] F. Siemieniako, M. Ostaszewski, T. Kuźmierowski, Analysis of requirements for exoskeleton construction. *Int. J. of Applied Mechanics and Engineering*, Vol.15, nr 3, 2010, pp. 841-846.