TECHNOLOGICAL AND ECONOMIC DEVELOPMENT OF ECONOMY
Baltic Journal on Sustainability
2009
15(3): 377–394

AN APPROACH OF MULTI-AGENT CONTROL OF BIO-ROBOTS USING INTELLIGENT RECOGNITION DIAGNOSIS OF PERSONS WITH MOVING DISABILITIES

Antanas Andrius Bielskis[1], Dalė Dzemydienė[2], Vitalij Denisov[3], Arūnas Andziulis[4], Darius Drungilas[5]

[1, 3, 4, 5] Klaipėda University, Manto g. 84, 92294 Klaipėda, Lithuania
E-mail: [1] andrius.bielskis@ik.ku.lt; [3] vitalij.denisov@ik.ku.lt; [4] arunas@ik.ku.lt; [5] dorition@gmail.com

[2] Mykolas Romeris University, Ateities g. 20, 08303 Vilnius, Lithuania
E-mail: daledz@mruni.lt

Received 4 March 2009; accepted 20 August 2009

Abstract. The aims of this research are focused on the construction of intellectualized equipments for people with moving disabilities to help them in sustainable integration into environment. The problem is to reveal main components of diagnosis of disabled persons, as well as to develop decision making models which are integrated into the control mechanisms of the special equipments, that are assigned to the class of bio-robots. This paper analyses the approach of the construction of such type of bio-robots with possibilities to integrate different knowledge representation techniques for the development of the reinforcement framework with multiple cooperative agents for the recognition of the diagnosis of emotional situation of disabled persons. Large-scale of multi-dimensional recognitions of emotional diagnosis of disabled persons often generate a large amount of multi-dimensional data with complex recognition mechanisms, based on the integration of different knowledge representation techniques and complex inference models. Sensors can easily record primary data; however, the recognition of abnormal situations, cauterisation of emotional stages and resolution for certain type of diagnosis is an oncoming issue for bio-robot constructors. The research results present the development of multi-layered model of this framework with the integration of the evaluation of fuzzy neural control of speed of two wheelchair type robots working in real time by providing moving support for disabled individuals. An approach for representation of reasoning processes, using fuzzy logical Petri nets for evaluation of physiological state of individuals is presented. The reasoning is based on recognition of emotions of persons during their activities.

Keywords: multiple agent system control, bio-robots, distributed information systems, knowledge representation techniques, fuzzy logic, neural networks, Petri nets.

Reference to this paper should be made as follows: Bielskis, A. A.; Dzemydienė, D.; Denisov, V.; Andziulis, A.; Drungilas, D. 2009. An approach of multi-agent control of bio robots using intelligent recognition diagnosis of persons with moving disabilities, *Technological and Economic Development of Economy* 15(3): 377–394.

ISSN 1392-8619 print/ISSN 1822-3613 online doi: 10.3846/1392-8619.2009.15.377-394
http://www.tede.vgtu.lt

1. Introduction

The developing processes of intelligent systems with adaptive e-services are complex and important issues for providing user-friendly e-health and e-social care for people with moving disabilities. Such systems include different intellectual components for the control and monitoring of sensors, by supporting multi-agent activities and, in accordance to the recognition of certain situations, integrate the possibilities to affect and control the devices of disabled persons (Bielskis *et al.* 2008; Gricius *et al.* 2008; Kaklauskas *et al.* 2006).

The robots under development for medical care applications are based on a new conceptual understanding of several different scientific areas. Substantial works exist in the robotics literature on the mechanical design, modeling, gait generation and implementation of adulatory robotic prototypes (Sfakiotakis, Tsakiris 2007; Zavadskas *et al.* 2007, 2008a, b, c). New human-robotics interface, consisting in an eye-tracker interfaced with a transcranial magnetic stimulator device, is designed in mobile robots (Mariottini *et al.* 2007). The bio-robotic devices need the integration of the means of different knowledge interpretation techniques for making the intelligence medical diagnosis (Bernardi *et al.* 2008; Dzemydienė *et al.* 2008a, b; Samanta, Nataraj 2008; Treigys *et al.* 2008).

We recognize the possibilities to integrate different types of knowledge representation techniques and to construct the control sub-systems of bio-robot system. The control subsystem is working as on-line diagnostic systems of complex mechanisms with the cooperation of multi-agent's activities in recognizing human affect sensing.

Being able both to provide an intelligent accident preventive robot-based support for people with moving disabilities and to include affect sensing in Human Computer Interaction (HCI, in providing e-health care for people with moving disabilities), Human-Robot Interaction (HRI, for assisting tele-healthcare patients remaining autonomous), and Computer Mediated Communication (CMC, in providing adaptive user-robot friendly collaboration), such system should depend upon the possibility of extracting emotions without interrupting the user during HCI, HRI, or CMC (Mandryk, Atkins 2007; Bielskis *et al.* 2007; Pentland 2004).

Emotion is a mind-body phenomenon that is accessible at different levels of observation (social, psychological, cerebral and physiological). The models of an intelligent multi-agent based e-health care systems for people with moving disabilities are recently proposed by (Villon, Lisett 2006; Bielskis *et al.* 2008). The continuous physiological activity of a disabled person is being made accessible by the use of intelligent agent-based bio-sensors coupled with computers.

The aims of this research are devoted to the investigations of the integration of different knowledge representation techniques for the development of the reinforcement framework within multiple cooperative agents' activities for the recognition of the prediction criteria of diagnosis of the emotional situation of disabled persons. The research results present further development of a multi-layered model of this framework with the integration of the evaluation of fuzzy neural control of speed of two wheelchair type robots working in real time by providing moving support for disabled individuals. The approach of reasoning by using fuzzy logical Petri nets (Jiang, Zheng 2000; Dzemydienė 2001) is described to define physiological state of disabled individuals by recognizing their emotions during their relaxation activities based on playing computer games.

2. An adaptive control of robot motion in the system

The proposed reinforcement framework of intelligent remote interaction of bio-robots is based on the distributed information systems with important personal data of the patients and of monitoring sensor's data. The framework is presented at Fig. 1. It includes two adaptive moving wheelchair-type robots which are remotely communicating with two wearable human's affect sensing bio-robots. To capture towards e-social and e-health care context relevant episodes based on humans affect stages (Vilon, Lisett 2006), the context aware sensors are incorporated into the design of the Human's Affect Sensing Bio-Robot-x (*HASBR-x*) for every disabled individual, and information based on these episodes is used by local Intelligent Decision Making Agent-x (*IDMA-x*) to control every intelligent support providing robot.

This framework allows a multi-sensor data fusion before transmitting the data to the Remote Control Server (RCS) to minimize the TCP/IP bandwidth usage. Multi-agent based adaptive motion control of both robots is based on an adaptive Fuzzy Neural Network Control (FNNC) in according to the approach shown in Fig. 2. The architecture of the FNNC controller represents an approach of the Adaptive Neural Fuzzy Inference System, the ANFIS that combines the field of fuzzy logic and neural networks shown in Fig. 2a (Rubaai *et al.* 2005).

The possibility to learn about the nonlinear dynamics and external disturbances of the motor speed controller with a stable output, small steady error, and fast disturbance rejection is integrated in this framework. At the k-th moment, the difference between motor speed reference value $v(k)$ and motor speed output value $v_o(k)$ is split to speed error $e(k)$ and speed error change $\Delta e(k)$.Those values are used by the proposed in (Jiang, Zheng 2000)

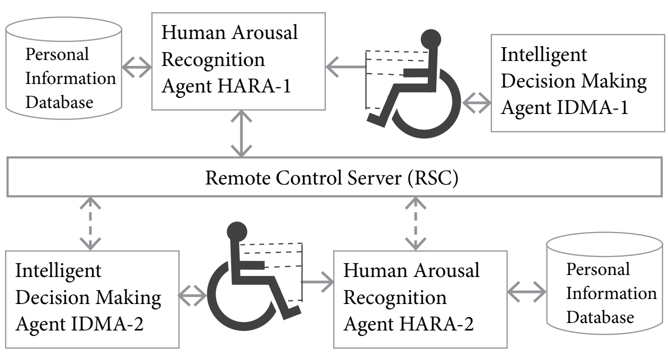
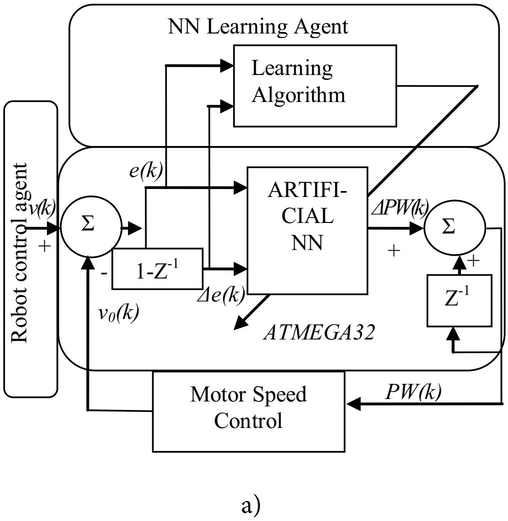


Fig. 1. The reinforcement framework of an intelligent remote bio-robots interaction based on distributed information systems



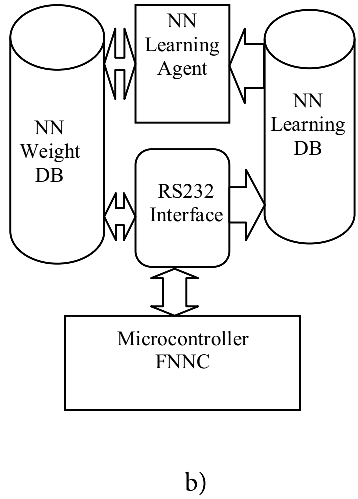


Fig. 2. Multi-agent based adaptive robot motor speed control system: a) Modified agent based adaptive FNNC-type DC motor speed controller, according to (Rubaai *et al.* 2005), b) Agent-based NN learning system (Gricius *et al.* 2008)

NN Learning Agent presented on Fig. 2b for the learning of artificial neural network *Artificial NN* on Fig. 2a as well as 2^{nd} order input vector of the *Artificial NN*. The output of the Artificial NN generates percentage value of pulse width change $\Delta PW(k)$ to describe how much pulse width value $PW(k)$ of the real motor speed control value at the moment k should be changed. This value is then generated in real time by the ATmega32 microcontroller to perform online calculating:

$$PW(k) = PW(k-1) + \Delta PW(k).$$

A simplified architecture of the neural-fuzzy controller (Rubaai *et al.* 2005) is presented on Fig. 3. The layer 1 in Fig. 3 represents inputs $X = e(k)$ and $Y = \Delta e(k)$ to the fuzzy neural controller, the speed error $e(k)$ and the change in speed error $\Delta e(k) = e(k) - e(k-1)$, respectively. The layer 2 consists of 7 input membership nodes with four membership functions, A_1, A_2, A_3, and A_4, for input X and three membership functions, B_1, B_2, and B_3 for input Y, the membership value specifying the degree to which an input value belongs to a fuzzy set is determined in this layer. The triangular membership function is chosen owing to its simplicity. For the change in motor speed error $\delta e(k)$, the initial values of the premise parameters (the corner coordinates a_j, b_j and c_j of the triangle) are chosen so that the membership functions are equally spaced along the operating range of each input variable. The weights between input and membership level are assumed to be unity. The output of neuron $j = 1, 2, 3$, and 4 for input $i = 1$ and $j = 1, 2$, and 3 for input $i = 2$ in the second layer can be obtained as follows:

$$O_j^2 = \begin{cases} \dfrac{X_i - a_j}{b_j - a_j}, & \text{for positive slope of triangle, when } X_i \geq a_j \text{ and } X_i \leq b_j, \\ \dfrac{X_i - c_j}{b_j - c_j}, & \text{for negative slope of triangle, when } X_i \geq b_j \text{ and } X_i \leq c_j, \end{cases}$$

where a_j, b_j, and c_j are the corners of the j-th triangle type membership function in layer 2 and X_i is the i-th input variable to the node of layer 2, which could be either the value of the error or the change in error. The layer 1 in Fig. 3 represents inputs $X = e(k)$ and $Y = \Delta e(k)$ to the fuzzy neural controller, the speed error $e(k)$ and the change in speed error $\Delta e(k)=e(k)-e(k-1)$, respectively.

Layer 2 consists of 7 input membership nodes with four membership functions, A_1, A_2, A_3, and A_4 for input X and three membership functions, B_1, B_2, and B_3 for input Y, as shown in Fig. 3. The weights between input and membership level are assumed to be unity. Each node in Rule layer 3 of Fig. 3 multiplies the incoming signal and outputs the result of the product representing one fuzzy control rule. It takes two inputs, one from nodes A_1–A_4 and the other from nodes B_1–B_3 of layer 2. Nodes A_1–A_4 define the membership values for the motor speed error and nodes B_1–B_3 define the membership values for the change in speed error. Accordingly, there are 12 nodes in layer 3 to form a fuzzy rule base for two input variables, with four linguistic variables for the input motor speed error $e(k)$ and three linguistic variables for the input change in motor speed change error $\Delta e(k)$.

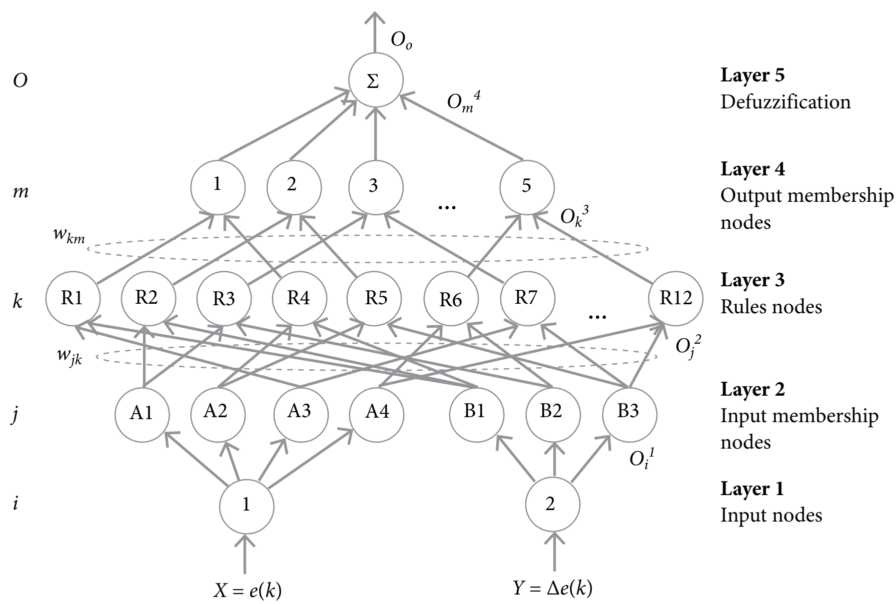


Fig. 3. Architecture of the neural-fuzzy controller by (Rubaai *et al.* 2005) for DC motor speed control of wheelchair type robot

The input/output links of layer 3 define the preconditions and the outcome of the rule nodes, respectively. The outcome is the strength applied to the evaluation of the effect defined for each particular rule. The output of neuron k in layer 3 is obtained as $O_k^3 = \prod_l w_{jk}^3 y_j^3$, where y_j^3 represents the j-th input to the node of layer 3 and w_{jk}^3 is assumed to be unity. Neurons in the output membership layer 4 represent fuzzy sets used in the consequent fuzzy rules. An output membership neuron receives inputs from corresponding fuzzy rule neurons and combines them by using the fuzzy operation union. This was implemented by the maximum function. The layer 4 acts upon the output of layer 3 multiplied by the connecting weights. These link weights represent the output action of the rule nodes evaluated by layer 3, and the output is given $O_m^4 = \max(O_k^3 w_{km})$, where the count of k depends on the links from layer 3 to the particular m-th output in layer 4 and the link weight w_{km} is the output action of the m-th output associated with the k-th rule. This level is essential in ensuring the system's stability and allowing a smooth control action. Layer 5 is the output layer and acts as a defuzzifier. The single node in this layer takes the output fuzzy sets clipped by the respective integrated firing strengths and combines them into a single fuzzy set. The output of the neuro-fuzzy system is crisp, and thus a combined output fuzzy set must be defuzzified. The sum-product composition method was used. It calculates the crisp output as the weighted average of the cancroids of all output membership functions as $O_o^5 = \frac{\sum_m \left(O_m^4 ac_m \cdot bc_m\right)}{\sum_m O_m^4 bc_m}$, where ac_m and bc_m for m = 1, 2, .., and 5 are the centres and widths of the output fuzzy sets, respectively. The values for the bc_m's were chosen to be unity. This scaled output corresponds to the control signal (percent duty cycle) to be applied to maintain the motor speed at a constant value. The only weights that are trained are those between layers 3 and layer 4 of Fig. 3. The back-propagation network is used to train the weights of this layer. The weights of the neural network were trained offline by using an open source type R-programming environment before they were used in the online real time experimental by applying the modified learning algorithm from (Rubaai *et al.* 2005):

Step (1): Calculate the error for the change in the control signal (duty cycle) for ATmega32-based microcontroller as $E_o = T_o - O_o^5$, where E_o, T_o, and O_o^5 are the output error, the target control signal, and the actual control signal;

Step (2): Calculate the error gradient $\delta_m = E_o \cdot \frac{\sum_{\substack{j=1 \\ j \neq m}}^{m-1} O_j^4 \left(ac_m - ac_j\right)}{\left(\sum_{j=1}^{m} O_j^4\right)^2}$, where ac_i for $i = 1 \ldots 5$ are the centres of the output fuzzy sets and O_j^4 is the firing strength from node j in layer 4;

Step (3): Calculate the weight correction $\Delta w_{km} = \eta \delta_m O_j^3$ to increasing the learning rate. Here Sejnowski – Rosenberg updating mechanism was used, which takes into account the effect of past weight, changes on the current direction of the moving in the weight space. This is given by $\Delta w_{km}(t) = \eta(1-\alpha)\delta_m O_m^3 + \alpha \Delta w_{km}(t-1)$, where α is a smoothing coefficient in the range of $0 \ldots 1{,}0$, and η is the learning rate;

Step (4): Update the weights $w_{km}(t + 1) = w_{km}(t) + \Delta w_{km}(t)$, where t is the iteration number. The weights linking the rule layer (layer 3) and the output membership layer (layer 4) are trained to capture the system dynamics and therefore minimize the ripples around the operating point.

3. Human computer interaction in the system

There are many different methods of recognizing physical state or behaviour by using data of wearer's emotion recognition sensors (Mandryk, Atkins 2007; Pentland 2004). In this paper, a modified Arousal – Valence model by (Mandryk, Atkins 2007) of Fig. 4 was used to discover information in real time for providing some friendly advices for a person with moving disabilities during his/her relaxation period based on playing computer games with computer as well as with his/her partner – another disabled person.

3.1. Fuzzy system for emotion recognition

The framework presented in Fig. 1 uses four emotion recognition sensors for each of disabled individual: the ECG (Electrocardiogram); the SCR (skin conductance response); the ST_H (skin temperature of head), and the ST_F (skin temperature of finger) to provide HR (heart rate), HRV_H (heart rate variability for the range of 0.15 to 0.4 Hz), HRV_L (heart rate variability for the range of 0.015 to 0.15 Hz), SCR, ST_H, and ST_F inputs for defining fuzzy values of arousal and valence (Fig. 5).

The principal scheme of the integration of different components of the modelling emotions is presented in Fig. 5 to provide HR(heart rate), HRV_H(heart rate variability for the range of 0.15 to 0.4 Hz), HRV_L (heart rate variability for the range of 0.015 to 0.15 Hz), SCR(skin conductance response), ST_H (skin temperature of head), and ST_F (skin temperature of finger) inputs to define fuzzy values of arousal and valence. The number of membership functions of

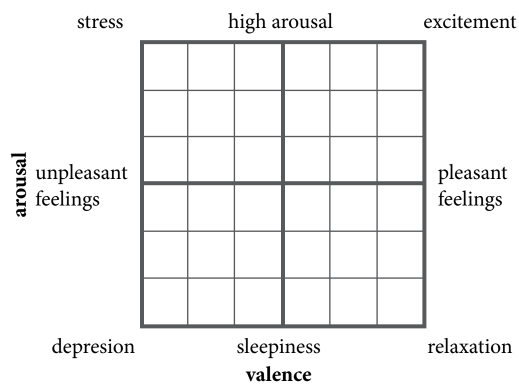


Fig. 4. An interpretation of the Affect Grid taken from (Mandryk, Atkins 2007) on having six levels of arousal and valence

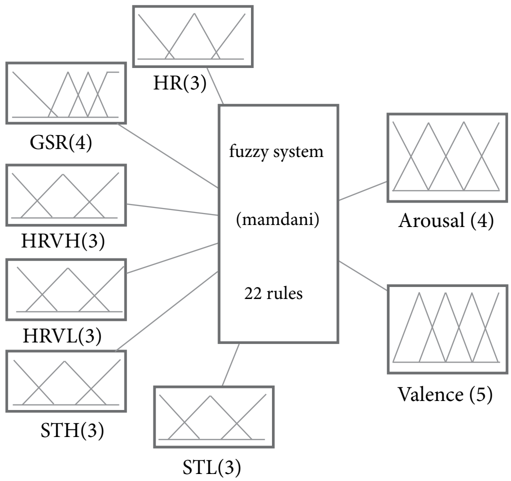


Fig. 5. The principal scheme of integrating different components of modelling emotions for defining fuzzy values of arousal and valence

Fig. 5 and 6 applied to that input or output follows the input/output labels. Within each input and output, there is a schematic representation of the location and form of the membership functions. In Fig. 5, all membership functions are triangular, while in Fig. 6 membership functions are trapezoidal, exhibited by the flat ceilings, rather than the peaked ceiling of a triangular membership function. The system in Fig. 6 uses 67 rules proposed in (Mandryk, Atkins 2007) to transform 2 inputs (the arousal and valence) into 5 outputs (fun, challenge, boredom, frustration, and excitement).

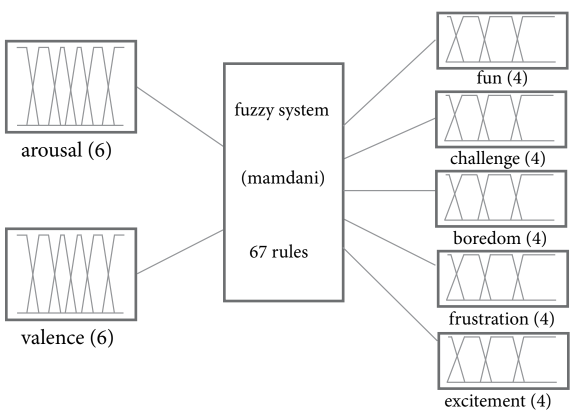


Fig. 6. Fuzzy system by (Mandryk, Atkins 2007) for the recognition of five emotional states (fun, challenge, boredom, frustration, and excitement) from arousal and valence

The model of fuzzy system by (Mandryk, Atkins 2007) for the recognition of five emotional states (fun, challenge, boredom, frustration, and excitement) from arousal and valence is shown in Fig. 6.

The computing results of fuzzy reasoning were obtained by the application of fuzzy logical Petri nets (Jiang, Zheng 2000). Classical Petri nets are defined as a structure $N = <S, T, F>$ where S means a set of places, T is a set of transitions and F is $F \subseteq (S\, x\, T) \cup (T\, x\, S)$, where $(\forall\, t \in T)(\exists\; p, q \in S)(p, t), (t, q) \in F$. Graphical representation is set up by the following symbols:

Places – by rings, *Transitions* – by rectangles, and *Relations* – by pointers between transitions and places or places and transitions. In classical Petri nets, there is a token placed if the expression is true (1) or not if it is false (0). Any *IF-THEN* rule is given of the form of

$$\text{IF } X_1 \text{ is } A_1 \text{ AND } X_n \text{ is } A_n \text{ THEN } Y \text{ is } B\,,$$

where $A_1, .., A_n$ and B are certain predicates characterizing the variables $X_1, ..., X_n$ and Y. The set of *IF-THEN* rules forms linguistic description:

$$R_1 := \text{IF } X_1 \text{ is } A_{11} \text{ AND ... AND } X_n \text{ is } A_{1n} \text{ THEN } Y \text{ is } B_1\,,$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$R_m := \text{IF } X_1 \text{ is } A_{m1} \text{ AND ... AND } X_n \text{ is } A_{mn} \text{ THEN } Y \text{ is } B_m\,,$$

where each transition of the result fuzzy Petri net corresponds to one rule of linguistic description. Models of Logical Petri Nets Applied to Transforming 89 Fuzzy Inference Rules to Constructing Support Information System for Bio-Robots are proposed in Table 1. In the Table 2, the set of 22 rules and corresponding transitions are proposed in concerting galvanic skin response, the GSR, heart rate, the HR, heart rate variability high, the HRV_H, heart rate variability low, the HRV_L, skin temperature of head, the ST_H, and skin temperature of finger, the ST_F into arousal and valence. In Table 3, the corresponding transitions of logical Petri nets are prescribed to the set of 67 rules used by (Mandryk, Atkins 2007) in concerting of arousal-valence space transformation into five modelled emotional states to converting arousal and valence into boredom, challenge, excitement, frustration, and fun.

3.2. Reasoning algorithms used by human arousal recognition agents

To derive emotions of user 1 and user 2 during their relaxation state of interactive playing of computer-based games, agents *HARA-1*, *HARA-2*, *IDMA-1*, and *IDMA-2* of Fig. 1 were programmed by using the reasoning algorithm of fuzzy logical Petri nets by (Pavliska 2006) (Fig. 7). This algorithm gets fuzzy Petri net as an input and creates a set of linguistic descriptions corresponding to each output place of fuzzy Petri net. Human arousal recognition agents HARA-1 and *HARA-2* of Fig. 1 were programmed to use these reasoning algorithms to create some friendly advices to disabled individuals who are taking part in the model of e-social care system for people with moving disabilities of Fig. 1 during their relaxation period based on playing computer games.

Table 1. Models of logical Petri nets (applied to transforming 89 fuzzy inference rules for designing the support information system in bio-robots)

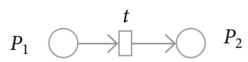
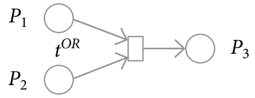
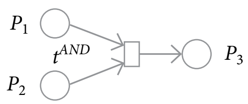
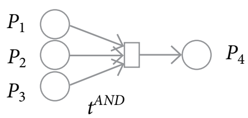
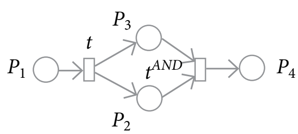
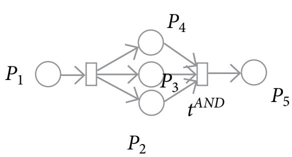
No	Applied LPN Model	Fuzzy Computing	Applied Transitions
1		$\alpha_2 = \lambda_t \alpha_1 \ if \ \alpha_1 \geq \theta_t$	T_1, T_3, T_{26}, T_{59}, T_{60}, T_{61}, T_{65}, T_{84}, T_{85}, T_{86}, T_{87}, T_{88}, T_{89}
2		$\alpha_3 = \lambda_{t^{OR}} \max\limits_{\substack{\alpha_t \geq \theta_{t^{OR}} \\ i=1\vee 2}} \{\alpha_1, \alpha_2\}$	T_2^{OR}, T_4^{OR}, T_{20}^{OR}, T_{21}^{OR}, T_{22}^{OR}
3		$\alpha_3 = \lambda_{t^{AND}} \min\limits_{\substack{\alpha_t \geq \theta_{t^{AND}} \\ i=1\wedge 2}} \{\alpha_1, \alpha_2\}$	T_{5-18}^{AND}, T_{23-25}^{AND}, T_{27-50}^{AND}, T_{62-64}^{AND}, T_{66-83}^{AND}
4		$\alpha_4 = \lambda_{t^{AND}} \min\limits_{\substack{\alpha_t \geq \theta_{t^{AND}} \\ i=1\wedge 2\wedge 3}} \{\alpha_1, \alpha_2, \alpha_3\}$	T_{19}^{AND}
5		$\alpha_2 = \lambda_t \alpha_1 \ if \ \alpha_1 \geq \theta_t$ $\alpha_3 = \lambda_t \alpha_1 \ if \ \alpha_1 \geq \theta_t$ $\alpha_4 = \lambda_{t^{AND}} \max\limits_{\substack{\alpha_i \geq \theta_{t^{AND}} \\ i=2\wedge 3}} \{\alpha_2, \alpha_3\}$	T_{51-52}, T_{55-58}
6		$\alpha_2 = \lambda_t \alpha_1 \ if \ \alpha_1 \geq \theta_t$ $\alpha_3 = \lambda_t \alpha_1 \ if \ \alpha_1 \geq \theta_t$ $\alpha_4 = \lambda_t \alpha_1 \ if \ \alpha_1 \geq \theta_t$ $\alpha_5 = \lambda_{t^{AND}} m \min\limits_{\substack{\alpha_i \geq \theta_{t^{AND}} \\ i=2\wedge 3\wedge 4}} \{\alpha_2, \alpha_3, \alpha_4\}$	T_{53-54}

Table 2. The set of rules and corresponding transitions for recognition of degree of emotional state

No	Rules	Transitions
1	If (GSR is *high)*, then (arousal is *high)*	T_1
2	If (GSR is *high*) or (HR is *high*), then (arousal is *high*)	T_2^{OR}
3	If (GSR is *mid-low*), then (arousal is *mid-low*)	T_3
4	If (GSR is *low*) or (HR is *low*), then (arousal is *low*)	T_4^{OR}
5	If (GSR is *low*) and (HR is *high*), then (arousal is *mid-low*)	T_5^{AND}
6	If (GSR is *high*) and (HR is *low),* then (arousal is *mid-high*)	T_6^{AND}
7	If (GSR is *high*) and (HR is *mid*), then (arousal is *high*)	T_7^{AND}
8	If (GSR is *mid-high*) and (HR is *mid*), then (arousal is *mid-high*)	T_8^{AND}
9	If (GSR is *mid-low*) and (HR is *mid*), then (arousal is *mid-low*)	T_9^{AND}
10	IF (HRV_H is *high*) and (HRV_L is *low*), then (valence is *very-high*)	T_{10}^{AND}

Continuation of **Table 2**

No	Rules	Transitions
11	IF (HRV_H is *low*) and (HRV_L is *high*), then (valence is *very-low*)	T_{11}^{AND}
12	IF (HRV_H is *medium*) and (HRV_L is *medium*), then (valence is *neutral*)	T_{12}^{AND}
13	IF (HRV_H is *high*) and (HRV_L is *medium*) then (valence is *high*)	T_{13}^{AND}
14	IF (HRV_H is *medium*) and (HRV_L is *high*), then (valence is *low*)	T_{14}^{AND}
15	IF (HRV_H is *medium*) and (HRV_L is *low*), then (valence is *high*)	T_{15}^{AND}
16	IF (HRV_H is *low*) and (HRV_L is *medium*), then (valence is *low*)	T_{16}^{AND}
17	IF (HRV_H is *high*) and (HRV_L is *high*), then (valence is *neutral*)	T_{17}^{AND}
18	IF (HRV_H is low) and (HRV_L is *low*), then (valence is *neutral*)	T_{18}^{AND}
19	IF (HR is *high*) and (HRV_H is *high*) and (HRV_L is *high*), then (valence is *high*)	T_{19}^{AND}
20	IF (ST_H is *high*) or (ST_L is *low),* then (valence is *low*)	T_{20}^{OR}
21	IF (ST_H is *low*) or (ST_L is *high*), then (valence is *high*	T_{21}^{OR}
22	IF (ST_H is *medium*) or (ST_L is *medium*), then (valence is *medium*)	T_{22}^{OR}

Table 3. Set of rules and corresponding transitions of logical Petri nets of transforming of the arousal-valence space

No	Rules	Transitions
23	If (arousal is *not very low*) and (valence is *mid-high*), then (fun is *low*)	T_{23}^{AND}
24	If (arousal is *not low*) and (valence is *mid-high*), then (fun is *low*)	T_{24}^{AND}
25	If (arousal is *not very low*) and (valence is *high*), then (fun is *medium*)	T_{25}^{AND}
26	If (valence is *very high*), then (fun is high)	T_{26}
27	If (arousal is *mid-high*) and (valence is *mid-low*), then (challenge is *low*)	T_{27}^{AND}
28	If (arousal is *mid-high*) and (valence is *mid-high*), then (challenge is *low*)	T_{28}^{AND}
29	If (arousal is *high*) and (valence is *mid-low*), then (challenge is *medium*)	T_{29}^{AND}
30	If (arousal is *high*) and (valence is *mid-high*), then (challenge is *medium*)	T_{30}^{AND}
31	If (arousal is *very high*) and (valence is *mid-low*), then (challenge is *high*)	T_{31}^{AND}
32	If (arousal is *very high*) and (valence is *mid-high*), then (challenge is *high*)	T_{32}^{AND}
33	If (arousal is *mid-low*) and (valence is *mid-low*), then (boredom is *low*)	T_{33}^{AND}
34	If (arousal is *mid-low*) and (valence is *low*), then (boredom is *medium*)	T_{34}^{AND}
35	If (arousal is *low*) and (valence is *low*), then (boredom is *medium*)	T_{35}^{AND}
36	If (arousal is *low*) and (valence is *mid-low*), then (boredom is *medium*)	T_{36}^{AND}
37	If (arousal is *mid-low*) and (valence is *very low*), then (boredom is *high*)	T_{37}^{AND}
38	If (arousal is *low*) and (valence is *very low*), then (boredom is *high*)	T_{38}^{AND}
39	If (arousal is *very low*) and (valence is *very low),* then (boredom is *high*)	T_{39}^{AND}
40	If (arousal is *very low*) and (valence is *low*), then (boredom is *high*)	T_{40}^{AND}
41	If (arousal is *very low*) and (valence is *mid-low*), then (boredom is *high*)	T_{41}^{AND}
42	If (arousal is *mid-high*) and (valence is *mid-low*), then (frustration is *low*)	T_{42}^{AND}
43	If (arousal is *mid-high*) and (valence is *low*), then (frustration is *medium*)	T_{43}^{AND}

Continuation of **Table 3**

No	Rules	Transitions
44	If (arousal is *high*) and (valence is *low*), then (frustration is *medium*)	T_{44}^{AND}
45	If (arousal is *high*) and (valence is *mid-low*), then (frustration is *medium*)	T_{45}^{AND}
46	If (arousal is *mid-high*) and (valence is *very low*), then (frustration is *high*)	T_{46}^{AND}
47	If (arousal is *high*) and (valence is *very low*), then (frustration is *high*)	T_{47}^{AND}
48	If (arousal is *very high*) and (valence is *very low*), then (frustration is *high*)	T_{48}^{AND}
49	If (arousal is *very high*) and (valence is low), then (frustration is *high*)	T_{49}^{AND}
50	If (arousal is *very high*) and (valence is *mid-low*), then (frustration is *high*)	T_{50}^{AND}
51	If (valence is *very low*), then (fun is *very low*) and (challenge is *very low*)	T_{51}
52	If (valence is *low*), then (fun is *very low*) and (challenge is *very low*)	T_{52}
53	If (valence is *high*), then (challenge is *very low*) and (boredom is *very low*) and (frustration is *very low*)	T_{53}
54	If (valence is v *very high*), then (challenge is *very low*) and (boredom is *very low*) and (frustration is *very low*)	T_{54}
55	If (valence is *mid-high*), then (boredom is *very low*) and (frustration is *very low*)	T_{55}
56	If (arousal is *very low*), then (challenge is *very low*) and (frustration is *very low*)	T_{56}
57	If (arousal is *low*), then (challenge is *very low*) and (frustration is *very low*)	T_{57}
58	If (arousal is *mid-low),* then (challenge is *very low*) and (frustration is *very low*)	T_{58}
59	If (arousal is *mid-high*), then (boredom is *very low*)	T_{59}
60	If (arousal is *high*), then (boredom is *very low*)	T_{60}
61	If (arousal is *very high),* then (boredom is *very low*)	T_{61}
62	If (arousal is *very low*) and (valence is *mid-high*), then fun is *very low*)	T_{62}^{AND}
63	If (arousal is *low*) and (valence is *mid-high*), then (fun is *very low*)	T_{63}^{AND}
64	If (arousal is *very low*) and (valence is *high*), then (fun is *low*)	T_{64}^{AND}
65	If (valence is *mid-low*), then (fun is *very low*)	T_{65}
66	If (arousal is *very low*) and (valence is *high*), then (boredom is *low*)	T_{66}^{AND}
67	If (arousal is *low*) and (valence is *mid-high*), then (boredom is *low*)	T_{67}^{AND}
68	If (arousal is *very low*) and (valence is *mid-high*), then (boredom is *medium*)	T_{68}^{AND}
69	If (arousal is *very high*) and (valence is *very low*), then (challenge is *medium*)	T_{69}^{AND}
70	If (arousal is *very high*) and (valence is *mid-high*), then (challenge is *medium*)	T_{70}^{AND}
71	If (arousal is *high*) and (valence is *low*), then (challenge is *low*)	T_{71}^{AND}
72	If (arousal is *high*) and (valence is *high*), then (challenge is *low*)	T_{72}^{AND}
73	If (arousal is *very high*) and (valence is *low*), then (challenge is *high*)	T_{73}^{AND}
74	If (arousal is *very high*) and (valence is high), then (challenge is *high*)	T_{74}^{AND}
75	If (arousal is *mid-high*) and (valence is *mid-high*), then (excitement is *low*)	T_{75}^{AND}
76	If (arousal is *high*) and (valence is *mid-high*), then (excitement is *medium*)	T_{76}^{AND}
77	If (arousal is *high*) and (valence is high), then (excitement is *medium*)	T_{77}^{AND}
78	If (arousal is *mid-high*) and (valence is high), then (excitement is *medium*)	T_{78}^{AND}
79	If (arousal is *very high*) and (valence is *mid-high*), then (excitement is *high*)	T_{79}^{AND}

Continuation of **Table 3**

No	Rules	Transitions
80	If (arousal is *very high*) and (valence is *high*), then (excitement is *high*)	T_{80}^{AND}
81	If (arousal is *very high*) and (valence is *very high*), then (excitement is *high*)	T_{81}^{AND}
82	If (arousal is *high*) and (valence is *very high*), then (excitement is *high*)	T_{82}^{AND}
83	If (arousal is *mid-high*) and (valence is *very high*), then (excitement is *high*)	T_{83}^{AND}
84	If (arousal is *mid-low*), then (excitement is *very low*)	T_{84}
85	If (arousal is *low*), then (excitement is *very low*)	T_{85}
86	If (arousal is *very low*), then (excitement is *very low*)	T_{86}
87	If (valence is *very low*), then (excitement is *very low*)	T_{87}
88	If (valence is *low*), then (excitement is very low)	T_{88}
89	If (valence is *mid-low*), then (excitement is *very low*)	T_{89}

```
input  : fuzzy Petri net: fpn
output: set of linguistic descriptions: lfln
lfln = ∅;
foreach output place op of fpn do // create linguistic description
    // create set of input variables (places) on whose op depends
    inputs = ∅;
    foreach input transition it of op do
        // add all inputs of transition it to inputs set
        inputs = inputs ∪ it.inputs;
    end
    // construct linguistic description (set of rules)
    rb = ∅;
    foreach input transition it of op do
        // construct rule corresponding to transition it
        rule = ∅;
        foreach element in from inputs do
            if rule ≠ ∅ then rule = rule + AND;
            if in ∈ it.inputs then
                rule = rule + in.name is edge(in, it).value;
            else
                rule = rule + in.name is UNDEF;
            end
        end
        rule = rule + THEN op.name is edge(it, op).value;
        rb = rb ∪ rule ; // add rule to rule base
    end
    lfln = lfln ∪ rb ; // add rule base to set of linguistic descriptions
end
```

Fig. 7. Reasoning algorithm by (Pavliska 2006) used for the implementation of fuzzy logical Petri nets of this framework

3.3. Scenario of using fuzzy logical Petri nets in the system

Let us consider the following scenario of the organization of some relaxation activities based on playing computer games by disabled individuals who are taking part in the model of e-social care system for people with moving disabilities of Fig. 1.

Step (1): The *IDMA-1* agent initiates the *IDMA-2* agent to asking *Wheelchair-2* robot to take the Human's Affect Sensing Bio-Robots *HASBR-1* and *2* from the shelf, bring them to user 1 and 2 for taking their on for both users, ask users to log on into the system to start relaxation activities based on playing of computer games.

Step (2): Agents *HARA-1* and *HARA-2* initiate starting of the game, record measured data into the *Personal Information Database* of each user, transforming emotion measurements into arousal-valence space, and infer level of emotions of each player.

Step (3): Human Computer Interaction (HCI) in the system adaptively generates friendly advices to each player into his/her *Personal Information Database* and periodically provides necessary e-game support advices for user1 and user2 based on their emotional states discovered during the game in real time.

Step (4): To propose self-adaptively controllable social care aware moving actions by robot 1 and 2 for a given user with moving disabilities, the Q-learning algorithm of Fig. 8 (Touzet, Watkins 1989) was implemented in the modified agent based adaptive FNNC-type DC motor speed controller of Fig. 2a for defining an optimal path of robots *Wheelchair 1* and *2* of Fig. 1 to go from randomly selected point A to point B under unknown environmental conditions.

The following fuzzy logical Petri net of this scenario is given on Fig. 9. In Fig. 9, *BLACK BOX 1* implements transitions T_1–T_{22}^{OR} (Table 2), and *BLACK BOX 2* represents T_{23}^{AND}–T_{89} (Table 3) transitions of Petri net.

```
Initialize Q(s,a) arbitrarily
Repeat (for each episode):
    Initialize s
    Repeat (for each step of episode):
    Choose a from s using policy derived from Q (e.g., ε-greedy)
    Take action a, observe r, s'
    Q(s,a) ← Q(s,a)+α[r+γmax_a' Q(s',a')-Q(s,a)]
    s←s' until s is terminal
```

Fig. 8. *Q* – learning: An off-policy TD control algorithm of robots *Wheelchair 1* and *2* by (Touzet, Watkins 1989)

4. Conclusions

In the process of the elaboration of the reinforcement framework with multiple cooperative agents for the recognition of an appropriate prediction criteria of diagnosis of emotional

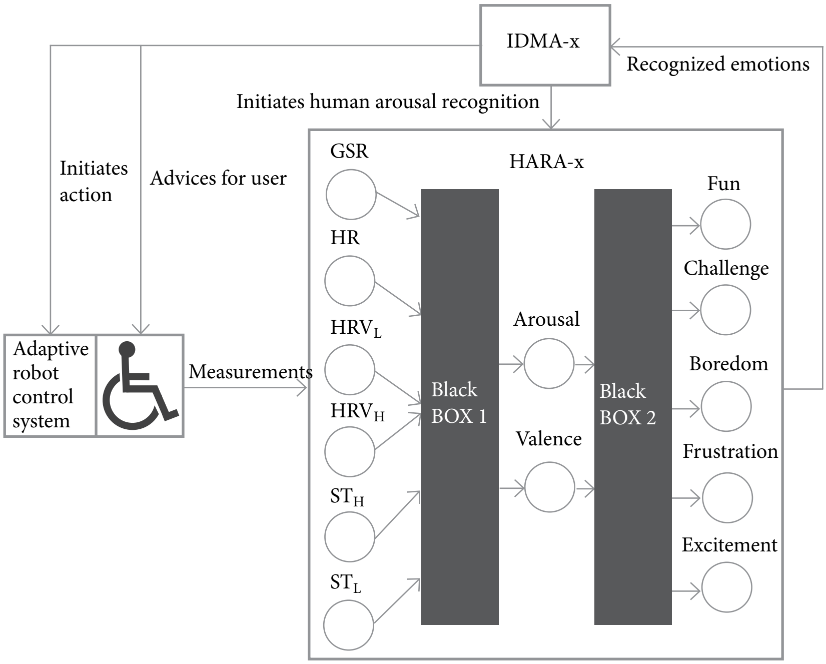


Fig. 9. Fuzzy logical Petri net for the scenario of supporting online relaxation activities for the users with moving disabilities

situation of disabled persons, an approach is presented based on further development of multi-layered model of this framework with the integration of the evaluation of fuzzy neural control of the speed of two wheelchair type robots working in real time. This was done by the implemention of the moving support for disabled individuals by using information based on emotion state of each disabled person.

The proposed framework uses four emotion recognition sensors for each disabled individual: the ECG (Electrocardiogram), the SCR (Skin Conductance Response), the ST_H (Skin Temperature of Head), and the ST_F (Skin Temperature of Finger) to provide HR (Heart Rate), HRV_H (Heart Rate Variability for the range of 0.15 to 0.4 Hz), HRV_L (Heart Rate Variability for the range of 0.015 to 0.15 Hz), SCR, ST_H, and ST_F inputs for defining fuzzy values of arousal and valence of disabled person.

The method of fuzzy reasoning by using fuzzy logical Petri nets based on transforming of arousal-valence space into five modelled emotional states to convert arousal and valence into boredom, challenge, excitement, frustration, and fun is described. The method allows both defining of physiological state of disabled individuals and giving them online advices based on recognition of their emotions during their relaxation activities based on playing computer games with each other and against the computer.

References

Bernardi, P.; Sanchez, E.; Schillaci, M.; Squillero, G.; Sonza Reorda, M. 2008. An effective technique for the automatic generation of diagnosis-oriented programs for processor cores, *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems* 27(3): 570–574. doi:10.1109/TCAD.2008.915541.

Bielskis, A. A.; Denisov, V.; Kučinskas, G.; Ramašauskas, O.; Romas, N. 2007. Modeling of human physiological parameters in an E-Laboratory by SOM Neural Networks, *Elektronika ir elektrotechnika* 3(75): 77–82.

Bielskis, A. A.; Denisov, V.; Drungilas, D.; Gricius, G.; Ramašauskas, O. 2008. Modeling of intelligent multi-agent based E-health care system for people with movement disabilities, *Elektronika ir elektrotechnika* 6(86): 37–42.

Dzemydienė, D. 2001. Temporal information management and decision support for predictive control of environment contamination processes, in *Proc. of Fifth East-European Conference 'Advances in Databases and Information Systems' ADBIS'2001*. Eds. A. Capliskas, J. Eder. Vilnius: Technika 1: 157–172.

Dzemydienė, D.; Maskeliūnas, S.; Jacobsen, K. 2008a. Sustainable management of water resources based on web services and distributed data warehouses, *Technological and Economic Development of Economy* 14(1): 38–50. doi:10.3846/2029-0187.2008.14.38-50.

Dzemydienė, D.; Maskeliūnas, S. ; Dzemyda, I. 2008b. Interoperability of information system components for monitoring of sewage and intelligent analysis of water resources, *Technological and Economic Development of Economy* 14(3): 260–278.

Gricius, G.; Drungilas, D.; Šliamin, A.; Lotužis, K.; Bielskis, A. A. 2008. Multi-agent-based e-social care system for people with movement disabilities, *Technological Research Works in Western Lithuania* 6: 67–77.

Jiang, Ch.; Zheng, Y. 2000. *Fuzzy Reasoning Based on Petri Nets*. Available from Internet: <*http://www.ici.ro/SIC/sic2000_3/art04.html*>.

Kaklauskas, A.; Zavadskas, E. K.; Ditkevičius, R. 2006. An intelligent tutoring system for constructions and real estate. 3rd International Conference on Cooperative Design, Visualization and Engineering, September 17–20, 2006, Mallora, Spain, Books Series: *Lecture Notes in Computer Science* 4101: 174–181. doi:10.1007/11863649_22.

Mandryk, R. L.; Atkins, M. S. 2007. A fuzzy physiological approach for continuously modelling emotion during interaction with play technologies, *Int. J. Human-Computer Studies* 6 R.L. 5: 329–347.

Mariottini, G. L.; Oriolo, G.; Prattichizzo, D. 2007. Image-based visual servoing for nonholonomic mobile robots using epipolar geometry, *IEEE Transactions on Robotics* 23(1): 87–100. doi:10.1109/TRO.2006.886842.

Pavliska, V. 2006. *Petri Nets as Fuzzy Modelling Tool*. Available from Internet: <http://irafm.osu.cz/research_report/84_rep84.pdf>.

Pentland, A. 2004. Health wear: medical technology becomes wearable, *IEEE Computer* 37(5): 42–49.

Rubaai, A.; Ofoli, A. R.; Burge, L.; Garuba, M. 2005. Hardware implementation of an adaptive network-based fuzzy controller for DC–DC converters, *IEEE Transactions on Industry Applications* 41(6): 1557–1565. doi:10.1109/TIA.2005.857461.

Samanta, B.; Nataraj, C. 2008. Automated diagnosis of cardiac state in healthcare systems using computational intelligence, *International Journal of Services Operations and Informatics* 3(2): 162–177. doi:10.1504/IJSOI.2008.019331.

Sfakiotakis, M.; Tsakiris, D. P. 2007. Biomimetic centering for undulatory robots, *The International Journal of Robotics Research* 26(11–12): 1267–1282. doi:10.1177/0278364907083394.

Touzet, C.; Watkins, 1989. *Q-learning for Robot*. Available from Internet: <http://www.up.univ-mrs.fr/Local/umr_6149/umr/page_perso/Touzet/Q-learning_for_Robots.pdf>.

Treigys, P.; Šaltenis, V.; Dzemyda, G.; Barzdziukas, V.; Paunksnis, A. 2008. Automated optic nerve disc parameterization, *Informatica* 19(3): 403–420.

Villon, O.; Lisett, Ch. 2006. A user-modelling approach to build user's psycho-physiological maps of emotions using bio-sensors, in *Proc. of IEEE Roman*, 269–276.

Zavadskas, E. K.; Kaklauskas, A.; Vlasenko, A. 2008a. Web-based VSA analyser decision support system for e-examination, in *8th International Conference on Fuzzy Logic and Intelligent Technologies in Nuclear Science "Computational Intelligence in Decision and Control", World Scientific Proceedings Series on Computer Engineering and Information Science*, September 21–24, 2008, Madrid, Spain, 1: 1153–1158.

Zavadskas, E. K.; Naimavičienė, J.; Kaklauskas, A.; Krutinis, M.; Vainiūnas, P. 2008b. Multi-criteria decision support system of intelligent ambient assisted living environment, in *25th International Symposium on Automation and Robotics in Construction*. ISARC-2008. Selected papers (June 26–29, Vilnius, Lithuania). Edited by E. K. Zavadskas, A. Kaklauskas, M. J. Skibniewski, 717–724.

Zavadskas, E. K.; Krutinis, M.; Kaklauskas, A.; Vainiūnas, P.; Naimavičienė, J.; Povilaitytė, L.; Tupėnaitė, L. 2008c. Model for multiple criteria analysis of integrated intelligent and built-up ambient assisted living environment, in *25th International Symposium on Automation and Robotics in Construction*, ISARC-2008. Selected papers (June 26–29, Vilnius, Lithuania). Edited by E. K. Zavadskas, A. Kaklauskas, M. J. Skibniewski, 725–730.

Zavadskas, E.; Kaklauskas, A.; Maciūnas, E.; Vainiūnas, P.; Marsalka, A. 2007. Real Estate's Market Value and a Pollution and health Effect Analysis, in 4th International Conference on Cooperative Design, Visualization and Engineering, September 16–20, 2007 Shanhai Peoples R China, *Lecture Notes in Computer Science* 4674: 191–200. doi:10.1007/978-3-540-74780-2_23.

DAUGIAAGENTIS BIOROBOTŲ VALDYMAS TAIKANT INTELEKTUALIZUOTUS ASMENIS SU JUDĖJIMO NEGALIA DIAGNOZĖS ATPAŽINIMO METODUS

A. A. Bielskis, D. Dzemydienė, V. Denisov, A. Andziulis, D. Drungilas

Santrauka

Šio mokslinio tyrimo tikslai yra nukreipti į intektualizuotų įrenginių, skirtų žmonėms su judėjimo negalia ir užtikrinančių jų būklės stebėseną ir darnaus judėjimo valdymo aplinkoje galimybes, kūrimą. Sprendžiami uždaviniai skirti neįgaliųjų diagnozės pagrindinių komponenčių tyrimams, sudarant lanksčius sprendimų priėmimo modelius, integruojamus į specialių įrenginių valdymo mechanizmus, kurie priskiriami biorobotų klasei. Straipsnyje pateikiami metodai, kaip konstruoti tokio tipo biorobotų sistemas, leidžiant skirtingų žinių vaizdavimo priemones integruoti į sistemą, kad būtų sukurta daugelio agentų bendradarbiavimo aplinka, skirta neįgaliųjų emocinės būklės diagnuozei analizuoti. Neįgaliųjų diagnozės procesams formalizuoti reikia kelių metodų, kurie grindžiami skirtingais žinių vaizdavimo formalizmais, skirtingų matų parametrų atpažinimo algoritmais. Sensorinės sistemos fiksuoja pirminius stebėsenos duomenis, tačiau nenormalioms situacijos būklėms atpažinti reikia sudėtingų išvedimo metodų, taikant lanksčias neuroninių tinklų valdymo priemones. Tyrimo rezultatai pateikiami per daugelio lygmenų darbo infrastruktūrą, kuri integruoja miglota logika grindžiamų neuroninių tinklų valdymo būdus, taikant juos neįgaliojo vežimėlio valdymo konstrukcijoms, kurios leidžia valdyti vežimėlio judėjimą automatiškai valdoma trajektorija. Miglota logika grindžiamų Petri tinklų taikymas leido pademonstruoti galimybes atpažinti neįgaliojo psichologinės būsenos pokyčius ir vertinti juos laike stebint pacientus skirtingą laiką.

Reikšminiai žodžiai: daugiaagentis sistemos valdymas, biorobotai, išskirstytosios informacinės sistemos, žinių vaizdavimo priemonės, miglota logika, neuroniniai tinklai, Petri tinklai.

Antanas Andrius BIELSKIS is professor, doctor habilitatis of the Department of Informatics of the Faculty of Nature Science and Mathematics of Klaipėda University (Lithuania). He holds a diploma of radio-engineering in 1959 of Kaunas Institute of Technology, PhD in electronic engineering in 1968 of Moscow Institute of Communications, and Doctor of Science in power electronics and communications in 1983 of the Institute of Electrodynamics of Academy of Science of Ukraine (Dr Habilitatis of Technical sciences in 1994). In 1959–1964, he was a designer, project manager at the Klaipėda Ship Design Institute, in 1964–1990 – senior lecturer, associate professor, head of the departments of electrical engineering and physics-mathematics, professor of the Klaipėda faculty of the Kaunas University of Technology, and from 1991 – professor of Klaipėda University. He is assigned as a member of the Joint doctoral evaluation committee in the fields P160, P170, P175 of the Klaipėda University and the Institute of Mathematics and Computer Science. He was: in 1993–1996 – a team member of the TEMPUS project JEP–6001 "Computer Based Environmental Studies" COBES-Lithuania; in 1998–1999 – a teem member of the COPERNICUS project CP–0636 "SME Software Support System"; in 2000–2003, – the coordinator of the Working Group "Theoretical Fundamentals of Informatics" (WG-1) within the SOCRATES/ERASMUS CDA project "MOCURIS" – "Modern Curriculum in Information Systems at Master Level". Since 1999 to the present, he is a visiting professor in the SOCRATES/ERASMUS exchange project between the Klaipėda University and the Wilhelmshaven University of Applied Science. He has published over 100 of research articles, two manual books and one monograph book. His research interests include: artificial intelligence methods, knowledge representation and decision support systems, ambient intelligence, and intelligent eco-social support systems.

Dalė DZEMYDIENĖ is professor, doctor, head of the Department of Informatics and Software Programs of the Social Informatics Faculty of the Mykolas Romeris University (Lithuania). She holds a diploma with honour of applied mathematics in specialization of software engineering in 1980, Dr in mathematics-informatics in 1995, habilitation doctor procedure in the field of social sciences of management and administration in 2004, and long time works at the Department of Software Engineering at the Institute of Mathematics and Informatics. She has published about 100 research articles, three manual books and one monograph book. She is an organizer of international conferences in the area of information systems and database development. She is the head of the Legal informatics section of Lithuanian Computer Society (LIKS), member of European Coordinating Committee for Artificial Intelligence (ECCAI) and member of Lithuanian Operation Research Association. Her research interests include: artificial intelligence methods, knowledge representation and decision support systems, evaluation of sustainable development processes.

Vitalij DENISOV is associated professor, Dr head of the Department of Computer Science at Klaipėda University. His research interests include mathematical and simulation modeling of complex systems, systems engineering, development of modeling and e-learning systems. He is the author of more than 70 research papers, a number of textbooks and educational software tools.

Arūnas ANDZIULIS is professor, doctor, head of the Department of Informatics engineering of the Faculty of Marine Engineering of the Klaipėda University (Lithuania). He holds a diploma with honour of physics in 1968 of Vilnius University, PhD in electronic engineering in 1968 of Kaunas Institute of Technology, habilitation doctor procedure in the field of transport engineering sciences in 2007, and long time works as a head, designer and project manager of the Department of microchip technology of the MRI "Venta". The author has published about 200 research articles and one manual books. He is an organizer of national conferences in the area of technical engineering. He is a member of the Legal informatics section of Lithuanian Computer Society (LIKS). His research interests include: artificial intelligence methods, operation research, nanotechnology and modelling and optimization of technical systems.

Darius DRUNGILAS is MSc. student at the Department of Computer Science, Klaipėda University. He graduated BSc degree in computer science, Klaipėda University (2007). He is the author of 2 scientific publications. Research interests: methods of artificial intelligence, agent-based modeling.