Scientific Bulletin of the „Petru Maior" University of Tîrgu Mureş
Vol. 9 (XXVI) no. 2, 2012, ISSN 2285 – 438X (Online), ISSN–L 1841 – 9267

ALGORITHM FOR TUNING THE CMAC REGULATOR SCALIN GAINS VIA AUTOMATIC SYSTEM STEP RESPONSE ANLYSIS

Horațiu-Ştefan GRIF

Electrical Engineering and Computer Science Department,
"Petru Maior" University of Tg. Mures
N. Iorga, no. 1, Tg. Mures, Romania
horatiu.grif@ing.upm.ro

ABSTRACT

The paper presents the tuning of a CMAC (Cerebellar Model Articulation Controller) regulator, with B-spline basis functions of order 3, implemented in an automatic daylight control system. After the tuning process of the regulator scaling gains, a set of ranges for scaling gains resulted. For these ranges of scaling gains the automatic lighting control system (ALCS) satisfied the desired performances. After the tuning process, the behavior of the ALCS in the presence of the illuminance disturbances was studied. At the final of the paper, an experimental tuning algorithm of the regulator scaling gains via ALCS step responses analysis is proposed. Even if the used experimental model of the process is a gross approximation of the real model of the process, using this experimental tuning algorithm, the designer can find a set of ranges of the regulator scaling gains for which the ALCS is stable and satisfy the desired performances.

Keywords: daylight, scaling gains, CMAC network, learning rate, visual comfort

1. Introduction

Even, the daylight system is a strategy, from lighting field, for electric energy saving [15], like the others lighting systems, is built to satisfy the visual comfort for the human user. Because the human being is unique, the human users may have different perception about the visual comfort and particularly may have different options about the reaction speed of the system to compensate the day light changes due to the sun positions or due to the clouds movement. For this purpose, is necessary a regulator tuning method via one parameter or many parameters which will allow the setting of the daylight system reaction speed which the human user desire. In [10] is proposed a tuning method of the regulators via scaling gains attached to the inputs and output of a fuzzy regulator. Modifying the scaling gains, the designer modifies the linguistic interpretation of the inputs and outputs of the fuzzy regulator, which involve different output values for the same inputs values. This observation offers the possibility to set different speed reaction of the regulator in an automatic daylight control system. The regulator tuning via scaling gains may be applied also in case of a regulator implemented with a Cerebellar Model Articulation Controller known in literature as the CMAC network and proposed by the Albus in [1]. The CMAC network, presented extensively and in comparative way with others neural structures in [2], can be viewed as a fuzzy-neural network, due to the using of the univariate basis functions in its structure. The using of this type of structure in automatic control field is preferred in general due to *"...its local generalization, extremely fast learning speed and easy implementation in software and hardware*" (Zhang, Cao, Lee and Zhao 2004, p.1) and for the particular case of the CMAC with B-spline basis functions is preferred because it "…*is a universal approximator for a smooth function and its derivatives*" (Wang and Lu 2003, p. 571). The tuning of a CMAC controller (regulator) via scaling gains and/or learning rate, and applied to a lighting process, it can find in: [3] where the lighting process is a 40W halogen lamp, the type of basis functions of the CMAC network are Gaussian and after the tuning process, the only parameter used for changing the speed reaction of the automatic lighting control system (ALCS) is the learning rate and; [5] where the lighting process is a 40W halogen lamp, the type of basis functions of the CMAC network are triangular and after the tuning process, the scaling gains are used for changing the speed reaction of the ALCS; [6] where the lighting process is a 20W halogen desk lamp, the type of basis functions of the CMAC network are B-spline of order 3 and the tuning process is concentrated only in the influence of the learning rate. An experimental algorithm for tuning the gains of a PID regulator via ALCS step response analysis is presented by the author of the current paper in [4], where the technological installation is based on two 36W fluorescent lamps. Considering the works from [3]-[6], in the current paper is presented the tuning of a CMAC regulator scaling gains via ALCS step responses analysis and is proposed an experimental algorithm for finding a set of ranges for scaling gains which allow human user to set the ALCS speed reaction which he wants and also the desired performances are satisfied by the ALCS. Even if in literature is preferred the CMAC network to be used in parallel with a classical controller (P, PD, PID) [12], [7], [9], adaptive supervisory controller [8] or the CMAC structure is combined with a fuzzy inference system [11], in present paper is preferred a control structure which imply an experimental model of the process for generating the learning signal for the CMAC network.

2. The experimental stand

The automatic lighting control system (ALCS) used in this paper is implemented by the experimental stand used in [6] and is presented in Figure 1. The experimental stand is composed by: the digital controller (1) – PIC18F4455, the execution element (2), the technological installation (3) – a 20W halogen desk lamp, the light sensor (4), the computer (5) for programming the digital controller and for acquisition the experimental data from digital controller, the disturbance iluminance generator (6) – an other 20W halogen desk lamp, the working plane (7).

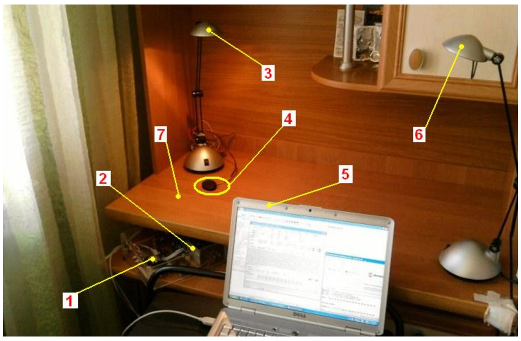

Fig. 1 - The experimental stand [6]

3. The block diagram of the automatic lighting control system

The configuration of the automatic lighting control system is presented in Figure 2.

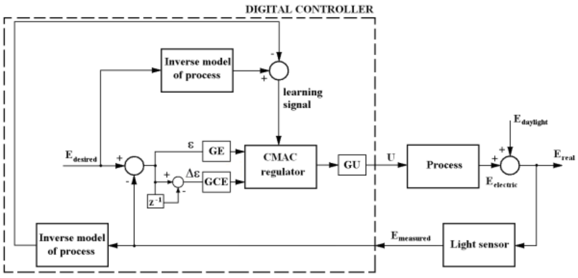

Fig. 2 - The block diagram of the ALCS

The ALCS try to maintain constant the illuminance (E_{real}) on working plan by compensating the daylight illuminance ($E_{daylight}$) variations with electric illuminance ($E_{electric}$) produced by the lighting process. The lighting process encapsulated the technological installation and the execution element. The control action (command), *U*, applied to the process is calculated by [3], [5], [6]

$$U(kT) = U(kT - T) + \Delta U(kT) \cdot GU \qquad (1)$$

The *GU* is a scaling gain used in the regulator tuning process.

The change in command (ΔU) is calculated by the regulator based on the values of its inputs: the control error (ε) multiplied by the scaling gain *GE* and the change in the control error ($\Delta\varepsilon$) multiplied by the scaling gain *GCE*. Like *GU*, the scaling gains *GE* and *GCE* are used in the regulator tuning process. The control error and change in control error are calculated by [3], [5], [6]

$$\varepsilon(kT) = E_{desired}(kT) - E_{measured}(kT) \qquad (2)$$

$$\Delta\varepsilon(kT) = \varepsilon(kT) - \varepsilon(kT - T) \qquad (3)$$

In (1)÷(3) the variable *T* represent the sampling time which have the same value like in [6]. The measured illuminance ($E_{measured}$) represents the real illuminance on working plane measured by the light sensor. The reference illuminance for ALCS represents the desired illuminance ($E_{desired}$) on working plan or, in other words, the target illuminance which have the ALCS to achieve on working plane.

The CMAC regulator (implemented with a CMAC network) needs a learning signal which is generated using an inverse model of the process. The inverse model of the process is obtained from an experimental direct model of the process. The experimental direct model of the process (Figure 3) represents a look-up table with measured data at the input and output of the process. The training of CMAC network is performed on-line using the Delta learning rule with the learning rate $\gamma = 0.01$.

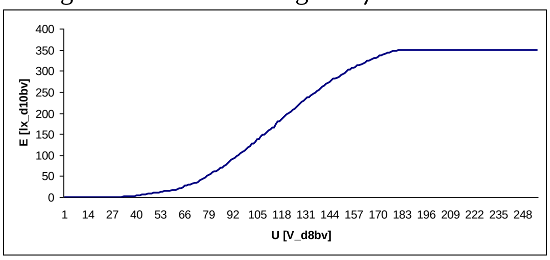

Fig. 3 - The experimental direct model of the process [6]

The internal structure of the CMAC regulator is the same like the one used in [6]. Describing shortly, the CMAC network have the following structure: the universe of discourse of each input variable has attached 3 over layers; each layer is divided in 6 equal intervals; each layer presents adjacent univariate B-spline basis functions of order 3 with non-overlapping supports (Figure 4); the support of a basis functions is 3 intervals length; on each layer the outputs of basis functions attaché to the two input variables are connected using linguistic *and* which is implemented by the product operator.

The limits of the universe of discourse of the control error variable of the regulator was calculated using (2) where: $E_{desired}$ = 290 lx_{d10bv}, $min(E_{measured})$ = 0 lx_{d10bv} and $max(E_{measured})$ = 350 lx_{d8bv}. The "*d10bv*" represents the abbreviation of "digital 10 bits value" and represents the final value of illuminance after the conversion of the measured illuminace on working plane with the 10 bits AD converter. The limits of the universe of discourse of change in control error variable were settled experimental to the same values as in the case of the control error variable.

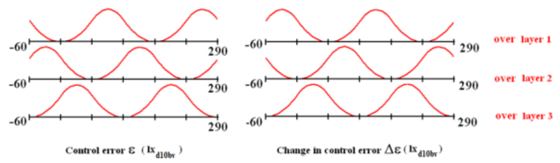

Fig. 4 - The arrangement of the B-spline basis functions of order 3 on the overlays attached to the inputs of regulator [6]

4. Experimental results

Always, before the running of an automatic control system (ACS), is necessary to establish a set of performances which the ACS has to achieves. For the present study the performances are imposed by the human eye perception of the user: the illuminance on working plane have to free of illuminance oscillations which can be detected by the human eyes and are interpreted as a visual discomfort. For this purpose the overshoot of the ALCS step response have to be smaller than 5%, and the steady state error have to be included in the range [-5%$E_{desired}$, 5%$E_{desired}$] lx_{d10bv} = [-14.5 , 14.5] lx_{d10bv}, where $E_{desired}$ = 290 lx_{d10bv}.

To achieve these performances using the scaling gains (*GE*, *GCE*, *GU*) the author performed the following steps.

Step 1. The CMAC network learning rate value was selected analyzing the step response family of the ALCS presented in [6] and acquired for different values of the learning rate. Even, in the mentioned step response family, the minimum value for learning rate is γ = 0.05, for the present study was selected, by way of precaution, a smaller value for learning rate (γ = 0.01). The step response of the ALCS for γ = 0.01, *GE*=*GCE*=*GU*=1 is presented in Figure 5. Even the step response has an overshoot, because the illuminance variation take seconds, the overshoot and the variations of the steady state error are not perceived by the human user eyes.

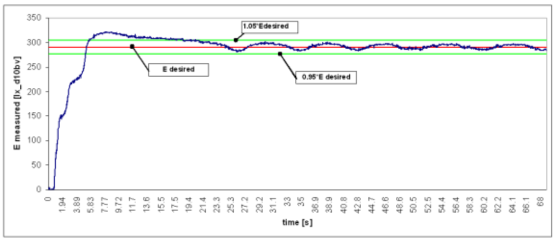

Fig. 5 - The step response of the ALCS (γ=0.01, GE=GCE=GU=1)

Step 2. Keeping constant the *GCE* = 1, *GU* = 1 and increasing the *GE* from 1 to 10 was acquired the corresponding step response family (Figure 6) of the ALCS. The increase of the *GE* will produce a decreasing of the transient response duration. The increase of the *GE* from 1 to 6 will decrease the overshoot from Figure 5. An increase of the *GE* over 6, will produce and increase an overshoot which is perceived by the human user eyes.

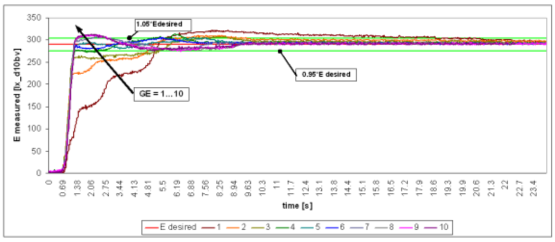

Fig. 6 - The step response family of the ALCS (γ=0.01, GE=1…10, GCE=GU=1)

Due to the above observation and analyzing the step response family from Figure 6 was selected *GE*=5. The corresponding step response of the ALCS is presented in Figure 7.

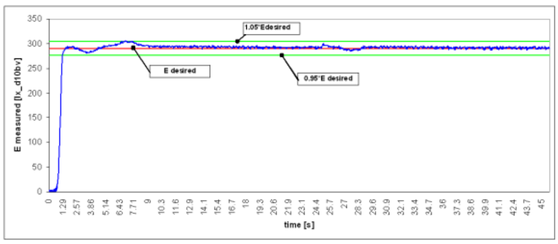

Fig. 7 - The step response of the ALCS (γ=0.01, GE=5, GCE=GU=1)

Step 3. Keeping constant the *GE* = 5, *GU* = 1 and increasing the *GCE* from 1 to 5 (the value of *GE*) was acquired the corresponding step response family (Figure 8) of the ALCS. The increasing of the *GCE* will produce almost the same transient response duration, and will not produce overshoot. Apparently is no relation between the *GCE* variation and the performance of the ALCS. The influence of the variation of the *GCE* is regarding the behavior of the steady state error.

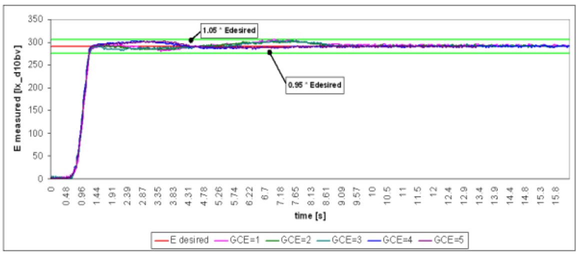

Fig. 8 - The step response family of the ALCS (γ=0.01, GE=5, GCE=1…5, GU=1)

Analyzing the detail of the step response family, regarding the behavior of the steady state error, and presented in Figure 9 for the change in the control error scaling gain was selected value *GCE* = 2. The corresponding step response of ALCS is presented in Figure 10.

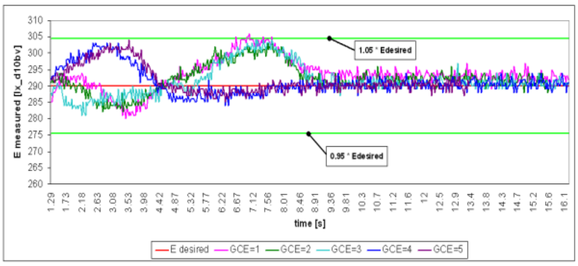

Fig. 9 – Detail of the step response family of the ALCS from Figure 8

Step 4. Keeping constant the *GE* = 5, *GCE* = 2 and decreasing the *GU* from 1 to 0.1 was acquired the corresponding step response family (Figure 10) of the ALCS. The decreasing of the *GU* scaling gain will reduce the risk of the overshoot but increase the transient response duration.

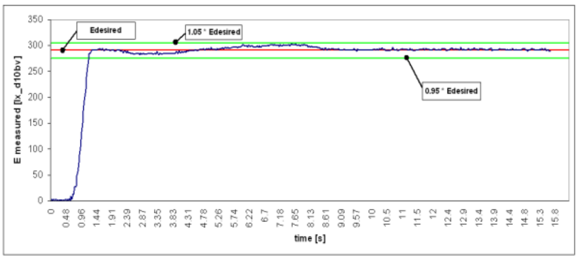

Fig. 10 - The step response of the ALCS (γ=0.01, GE=5, GCE=2, GU=1)

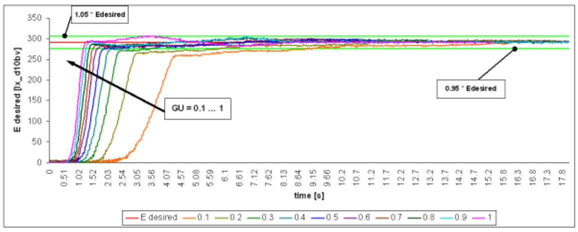

Fig. 11 - The step response family of the ALCS (γ=0.01, GE=5, GCE=2, GU=0.1 …1)

Analyzing the step response family from Figure 11, the author chose a small value for the scaling gain *GU* (*GU*=0.25).

Step 5. Taking the scaling gains *GE*=5, *GCE*=2 and *GU*=0.25 the following couple of proportions can be calculated:

$$(p1, p2) = (GCE/GE, GU/GE) = (0.4, 0.05) \quad (4)$$

Keeping constant the proportions (4) and increasing the *GE* scaling gain from 2 to 10 was acquired the corresponding step response family (Figure 12) of the ALCS.

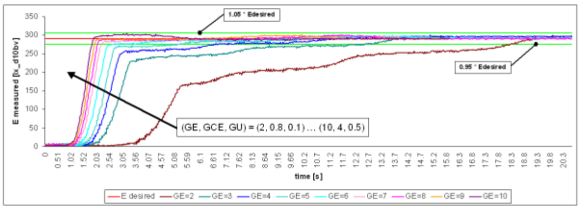

Fig. 12 - The step response family of the ALCS (γ=0.01, GE=2…10, p_1=0.4, p_2=0.05)

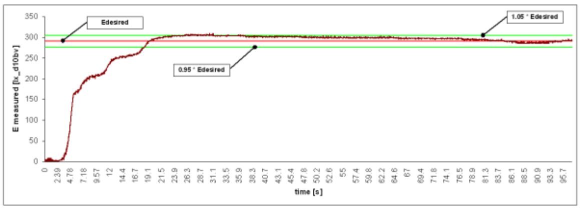

Fig. 13 - The step response of the ALCS (γ=0.01, GE=2, GCE=0.8, GU=0.1)

Analyzing the step response family of the ALCS from Figure 12 and the step response of the ALCS from Figure 13 the overshoot is smaller or equal to 5%$E_{desired}$ and the steady state error is in the range [-5%$E_{desired}$, 5%$E_{desired}$] lx_{d10bv}. The increasing of the scaling gains keeping constant the proportions p_1 and p_2 given by (4) will decrease the transient response duration.

Step 6. Considering the set of the triplets (*GE*, *GCE*, *GU*) for the step response family of ALCS from Figure 12 it has necessary to verify the stability of the ALCS. Taking the triplets (*GE*, *GCE*, *GU*)={(2, 0.8, 0.1), (10, 4, 0.5)} the stability of the ALCS was tested by disturbing the illuminance on working plane with the additional illumnance produced by the desk lamp (disturbance iluminance generator) denoted with 6 in Figure 1. The shape of the disturbance signal is presented in Figure 14.

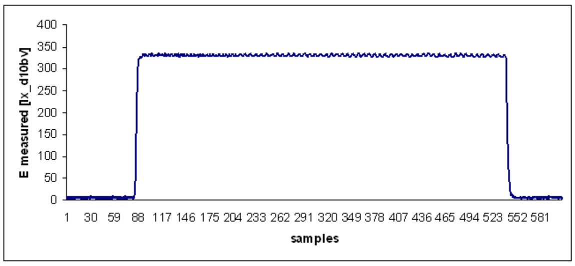

Fig. 14 – The shape of the disturbance signal

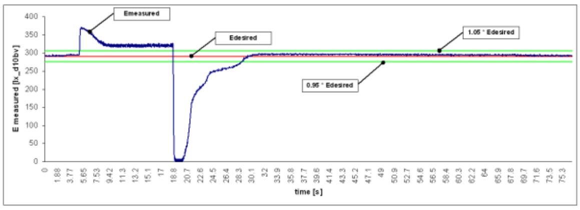

Fig. 15 – The behavior of the ALCS (γ=0.01, GE=2, GCE=0.8, GU=0.1) when is applied the disturbance signal

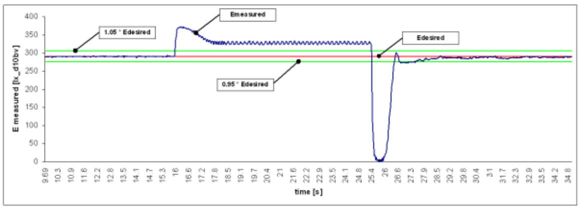

Fig. 16 – The behavior of the ALCS (γ=0.01, GE=10, GCE=4, GU=0.5) when is applied the disturbance signal

Considering the behavior of the ALCS from Figure 15 and Figure 16 it can say the ALCS is stable in the presence of the disturbances for the sets of scaling gains values considered in Figure 12.

5. The regulator scaling gains tuning via ALCS step response analysis algorithm

Considering the work from the previous section an experimental tuning algorithm for the regulator scaling gain can be proposed.

Step 1. Keeping constant the scaling gains (*GE*=*GCE*=*GU*=1) perform a study of the influence of the learning rate (γ) regarding the step response of the ALCS. For this purpose have to acquire a step response family of the ALCS when learning rate is variable. The recommended values are in the interval (0,1). Chose a value for the learning rate (denoted by γ_1) for which the ALCS satisfy the imposed performances or a part of them and follow the Step 2.

Step 2. Keeping constant γ_1 and the scaling gains *GCE*=*GU*=1 acquire a step response family of the ALCS when the scaling gain *GE* is variable (in the case of the presented CMAC regulator, increase the value of *GE* from 1 to the first number N for which the step response of the ALCS presents overshoot perceived by the human eye). Analyzing the step response family of the ALCS chose a value for $GE=GE_1$ for which the ALCS satisfy the imposed performances or a part of them and follow the Step 3. If the ALCS does not satisfy the imposed performances or after the passing of the next steps, the Step 7 is not satisfied go to Step 1.

Step 3. Keeping constant γ_1, $GE=GE_1$ and *GU*=1 acquire a step response family of the ALCS when the scaling gain *GCE* is variable (in the case of the presented CMAC regulator, increase the value of *GCE* from 1 to GE_1). Analyzing the step response family of the ALCS chose a value for $GCE=GCE_1$ for which the ALCS satisfy the imposed performances or a part of them and follow the Step 4. If the ALCS does not satisfy the imposed performances or after the passing of the next steps, the Step 7 is not satisfied go to Step 2.

Step 4. Keeping constant γ_1, $GE=GE_1$ and $GCE=GCE_1$ acquire a step response family of the ALCS when the scaling gain *GU* is variable (in the case of the presented CMAC regulator, decrease the value of *GU* from 1 to smaller value for which the transient response duration does not pass 10 seconds and increase the value of *GU* from 1 to the first number N for which the step response of the ALCS presents overshoot perceived by the human eye). Analyzing the step response family of the ALCS chose a value for $GU=GU_1$ for which the ALCS satisfy the imposed performances and follow the Step 5. If the ALCS does not satisfy the imposed performances or after the passing of the next steps the Step 7 is not satisfied go to Step 3.

Step 5. Perform the calculation of the proportions p_1 and p_2 between the scaling gains, using (4). Keeping constant the proportion p_1 and p_2, acquire a step response family modifying the scaling gain *GE*. The other two scaling gains are computed by

$$GCE = p_1 \cdot GE \tag{5}$$

$$GU = p_2 \cdot GE \tag{6}$$

Analyzing the step response family of the ALCS chose the range for *GE* (the ranges for *GCE* and *GU* results using the values of *GE* and the proportions p_1 and p_2) for which the ALCS satisfy the imposed performances and follow the Step 6. If, is impossible to chose a range considered by the designer wide enough, go to Step 4.

Step 6. For the ranges of the scaling gains determined in the Step 5 perform stability test for the ALCS. The ALCS stability testing it can achieve by: a) disturbing the illuminace on working plane with the electrical illuminance produced by a secondary lamp when the illuminance on working plane (E_{real}) is stabilized at the desired level ($E_{desired}$); b) disturbing the illuminance on working plane with daylight by covering and uncovering partial or total the window near the technological installation when the illuminance on working plane (E_{real}) is stabilized at the desired level ($E_{desired}$). After the stability test, set the final ranges for the scaling gains. For this ranges of scaling gains, ALCS must be stable and satisfy the imposed performances. Follow Step 7.

Step 7. If the ranges of the scaling gains are considered by the designer wide enough the tuning process is finished. If the ranges of the scaling gains are not considered by the designer wide enough, go to the Step 4.

Once the tuning process of the scaling gains is finished, the ALCS human user can select and set one of the multiple possible speed reaction of the ALCS, modifying just one parameter, the *GE* scaling gain. The other two scaling gains (*GCE* and *GU*) will be set automatically by multiplying *GE* with the corresponding proportion, p_1 or p_2.

6. Conclusions

A stable ALCS and multiple choices of the speed reactions of the ALCS represent enough reasons to recommend this type of system for integrations in daylight applications.

The algorithm presented in the present paper, the regulator scaling gains tuning via step response analysis become a comfortable tune tools in case of the control systems where the process has an unknown mathematical model and is possible to attach scaling gains to the regulator. The algorithm can be applied for tuning the scaling gains attached to fuzzy, fuzzy-neural, neural-fuzzy and neural regulators. In the case of the fuzzy regulators the Step 1 missing. The algorithm, with some modifications regarding the way of parameters modification and the numbers of steps, can be extended for tuning the parameters in case of regulators with the numbers of parameters grater than 3.

Even if the regulator presented in this paper have 4 parameters (learning rate and 3 scaling gains) the human user may chose the speed reaction of the ALCS which he consider to be proper for his use, acting on a single parameter, scaling gain *GE*.

For the ranges of the CMAC regulator scaling gains presented in the current paper, the ALCS can be used in those applications where the human user need to feel the illuminance changes due to the natural day light changes (e.g. home and office applications). To use the presented CMAC regulator in an ALCS for applications where from the human eye perception point of view the illuminance must be constant (e.g. design laboratory), which implies faster speed response of ALCS, supplementary studies are required.

References

[1] Albus, J.S. (1975), New Approach to Manipulator Control: The Cerebellar Model Articulation Controller (CMAC), *Transactions of the ASME Journal of Dynamic Systems, Measurement, and Control*, September 1975, pp. 220 – 227.

[2] Brown M. and Harris C. (1994), *Neurofuzzy Adaptive Modelling and Control*, Prentice Hall International (UK) Limited.

[3] Grif, H.S. (2010), Halogen Daylight Control System Based on CMAC Controller, *2010 IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR 2010)*, pp. 84-88.

[4] Grif, H.S. (2011), Pid Daylight Control System, *Scientific Bulletin of the “Petru Maior” University of Tg. Mures*, Vol. 8 (XXV) No. 1, pp. 12-16.

[5] Grif, H.S. and Dulău, M. (2011), Halogen Automatic Daylight Control System Based On Cmac Controller With Triangular Basis Functions, *Scientific Bulletin of the “Petru Maior” University of Tg. Mures*, Vol. 8 (XXV) No. 1, pp. 17-23.

[6] Grif, H.S., Modrea, A. and Rus, D. (2011), Fuzzy-Neural Automatic Daylight Control System, *Interdisciplinarity in Engineering International Conference (INTER-ENG2011)*, pp. 30-34.

[7] Jiang, Z. and Wang, S. (2003), A General Learning Scheme for CMAC-based Controller, *Neural Processing Letters*, No. 18, pp. 125–138.

[8] Lee, C.-H. and Wang, B.-H. (2009), Adaptive supervisory WCMAC neural network controller (SWC) for nonlinear systems, *Soft Computing*, No. 13, pp. 1–12.

[9] Lv, S., Wang, G., Yuan, Z., and Yang, J. (2006), Fuzzy CMAC with Online Learning Ability and Its Application, *Lecture Notes in Computer Science*, Volume 4221, 2006, pp 93-96.

[10] Passino, K.M. and Yurkovich, S. (1998), *Fuzzy Control*, Addison Wesley Longman, Inc.

[11] Sabourin, C., Yu, W. and Madani, K. (2012), Gait Pattern Based on CMAC Neural Network for Robotic Applications, *Neural Process Letters*, Online First Articles, pp.1-19.

[12] Sun W., Wang C., Bu D., Liu S., Wu B., and Ouyang M. (2012), A Fuzzy Cerebellar Model Articulation Controller Based Visual Servo System for Robot, *International Journal of Control, Automation, and Systems*, Vol. 10, No.2, pp. 430-436.

[13] Zhang, L., CAO, Q., LEE, J., and ZHAO, Y. (2004), A Modified CMAC Algorithm Based on Credit Assignment, *Neural Processing Letters*, No. 20, pp. 1–10.

[14] Wang, S. and Lu, H. (2003), Fuzzy system and CMAC network with B-spline membership/basis functions are smooth approximators, *Soft Computing*, No. 7, p. 566–573.

[15] *** (2000), *Ghidul Centrului de Ingineria Iluminatului. Iluminatul interior (The Guide of the Lighting Engineering Centre. Interior Light)*, Ed. Mediamira, Cluj-Napoca, 2000.