

## FUZZY-NEURAL AUTOMATIC DAYLIGHT CONTROL SYSTEM

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### ABSTRACT

*The paper presents the design and the tuning of a CMAC controller (Cerebellar Model Articulation Controller) implemented in an automatic daylight control application. After the tuning process of the controller, the authors studied the behavior of the automatic lighting control system (ALCS) in the presence of luminance disturbances. The luminance disturbances were produced by the authors in night conditions and day conditions as well. During the night conditions, the luminance disturbances were produced by turning on and off a halogen desk lamp. During the day conditions the luminance disturbances were produced in two ways: by daylight contributions changes achieved by covering and uncovering a part of the office window and by turning on and off a halogen desk lamp. During the day conditions the luminance disturbances, produced by turning on and off the halogen lamp, have a smaller amplitude than those produced during the night conditions. The luminance disturbance during the night conditions was a helpful tool to select the proper values of the learning rate for CMAC controller. The luminance disturbances during the day conditions were a helpful tool to demonstrate the right setting of the CMAC controller.*

**Keywords:** daylight control system, CMAC structure, basis functions, B-spline, learning rate

### 1. Introduction

The Cerebellar Model Articulation Controller (CMAC) proposed by Albus in [1] as a model of the information processing activities within the cerebellum [8] is preferred due to its local generalization, extremely fast learning speed and easy implementation in software and hardware [7],[9].[5] In the last decade different training algorithms for CMAC neural network as functions, data mapping approximators or in control applications have been investigated.[5] In daylight control topic, Grif implemented and tuned a CMAC structure controller with Gaussian basis functions in [4], Grif and Dulău implemented and tuned a CMAC structure controller with triangular basis functions in [5]. Both papers also present the behavior of the daylight control system with the same technological installation (based on a 40W halogen lamp).

### 2. The control system configuration and the experimental stand

The control structure applied to the lighting process is depicted in fig. 1 where:  $E_{desired}$  – the desired luminance;  $E_{measured}$  – the measured luminance;  $E_{real}$  – the luminance;  $E_{daylight}$  – the daylight luminance;  $E_{electric}$  – the luminance due to electric light;  $\varepsilon$  - control error;  $\Delta\varepsilon$  - change in control error;  $U$  – control action.

Implementing the controller as incremental type [6], [4], [5] the control action is calculated by:

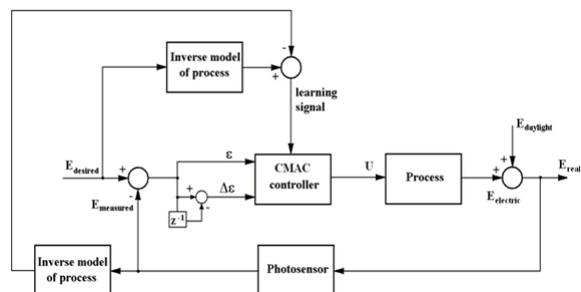
$$U(kT) = U(kT - T) + \Delta U(kT) \quad (1)$$

The  $\varepsilon$  and  $\Delta\varepsilon$  are given by:

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

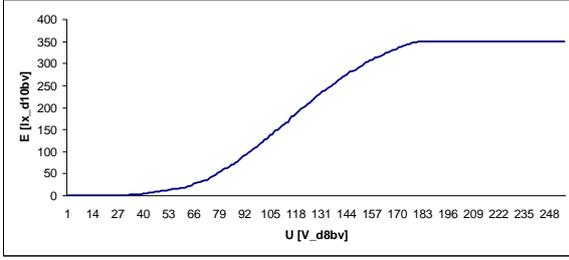
$$\Delta\varepsilon(kT) = \varepsilon(kT) - \varepsilon(kT - T) \quad (3)$$

where  $T$  is the sampling time.



**Fig. 1 - The block diagram of the control system**

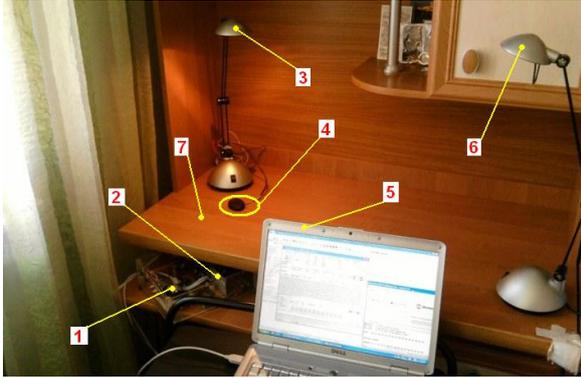
Because the model of the process is unknown an experimental model was used. The experimental direct model of process, a look up table (LUT) of measured data at the input and the output of process, are presented in fig. 2.



**Fig. 2 - The experimental model of the process (the direct model)**

The meaning of the notation *d8bv* is “digital 8 bits value” and the meaning of the notation *d10bv* is “digital 10 bits value”. A value followed by  $lx_{d10bv}$  represents the value of the measured luminance on working plane converted by a 10 bits AD converter. A value followed by  $V_{d8bv}$  represents a digital 8 bit value which will be converted in an analogical voltage by an 8 bits DA converter in case of the control action.

Figure 3 shows the experimental stand composed of: (1) calculation equipment (PIC 18F4455) which supports the CMAC controller, (2) the execution element, (3) the technological installation based on one 20W halogen desk lamp (controlled desk lamp), (4) light sensor, (5) computer for programming the calculation equipment and for acquisition data from calculation equipment, (6) 20W halogen desk lamp (disturbance desk lamp) used for generating luminance disturbance on desk surface, (7) the desk surface (working plane).



**Fig. 3 - The experimental stand**

The measured luminance on the desk surface may be the luminance obtained by one of the following three situations:

- the sum of the luminances produced by the controlled desk lamp and the daylight contribution through the office windows;
- the sum of the luminances produced by the controlled desk lamp and the luminances produced by the disturbance desk lamp;
- the sum of the luminances produced by the two halogen desk lamps and the daylight contribution.

### 3. The CMAC controller

As is presented in fig. 1 the controller have

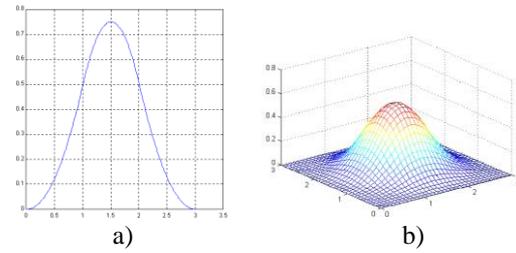
two inputs and one output. Following the used description of controller in [4] and [5] the design choices for CMAC controller are:

- control error ( $\varepsilon$ ) and the change in control error ( $\Delta\varepsilon$ ) are the input variables of controller;
- the variation in command ( $\Delta U$ ) is the output variable of the CMAC controller;
- the basis functions are implemented with B-spline function type of order 3 (fig. 4a) given by [2]:

$$B_{k,j}(x) = \left[ \frac{x - \lambda_{j-k}}{\lambda_{j-1} - \lambda_{j-k}} \right] B_{k-1,j-1}(x) + \left[ \frac{\lambda_j - x}{\lambda_j - \lambda_{j-k+1}} \right] B_{k-1,j}(x) \quad (4)$$

$$B_{i,j}(x) = \begin{cases} 1, & x \in [\lambda_{j-1}, \lambda_j) \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

where  $\lambda_j$  is the  $j^{\text{th}}$  knot (each basis function support is divided in three equal intervals, the start and the end of each interval are called *knots*);

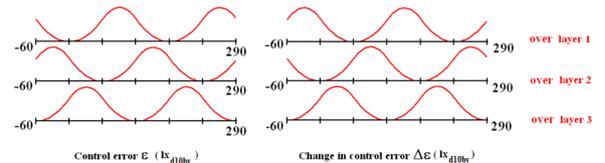


**Fig. 4 - B-spline basis function of order 3: a) one-dimensional; b) two-dimensional [3]**

- the generalization parameter of CMAC,  $\rho$ , is set to value 3;

- on each layer, the basis functions (one-dimensional functions) attached to  $\varepsilon$  and those attached to  $\Delta\varepsilon$  are connected together using the linguistic *and* and the resulting two-dimensional basis functions. Using the product operator to implement the connector *and* the two-dimensional basis functions will have the shape like the one depicted in fig. 4b;

- each layer attached to an input variable was divided in equal intervals by 5 interior knots (fig. 5); the width of each basis function was determined by multiplying the width of an interval by the value of generalization parameter  $\rho$ ;



**Fig. 5 - The displacement of the basis functions on the overlays attached to the inputs of controller when  $d=(1,2)$  and  $\rho=3$**

- the overlay displacement vector is set as in [4], [5] to  $d=(1,2)$ , the basis functions displacement for each input of controller are presented in fig. 5;

- the universe of discourse for the input variable  $\varepsilon$  was set to the range  $[-60, 290]$  ( $lx_{d10bv}$ ).

Considering the desired luminance on the desk surface set to  $290lx_{d10bv}$  the universe of discourse of  $\varepsilon$  was determined as follows: replacing in (2) the value of desired luminance and the minimum converted value of measured luminance with the 10 bits A/D converter ( $0lx_{d10bv}$ ) will produce the maximum value,  $\varepsilon_{max} = 290lx_{d10bv}$ , of the universe of discourse; replacing in (2) the value of desired luminance and the maximum luminance contribution of the halogen lamp (the lamp no. 3 from fig. 3) converted by 10 bits D/A converter ( $350lx_{d10bv}$ ) will produce the minimum value,  $\varepsilon_{min} = -60lx_{d10bv}$ , of the universe of discourse.

- the universe of discourse for the input variable  $\Delta\varepsilon$  are set experimentally to the range  $[-60,290]lx_{d10bv}$ .

- the two-dimensional input space of the CMAC controller (there are two input variables) is converted by the two-dimensional basis functions layers in a higher dimensional space (there are 22 two-dimensional basis functions) in which only a small number of variables have non-zero values (the  $\rho$  two-dimensional basis functions are active at all times). The output of the CMAC controller represents the weighted sum of the active two-dimensional basis functions outputs. The weights are stored in a vector with 22 components. The active weights (corresponding to the active two dimensional basis functions) are modified according to the learning signal of the Delta learning rule.

#### 4. Experimental results

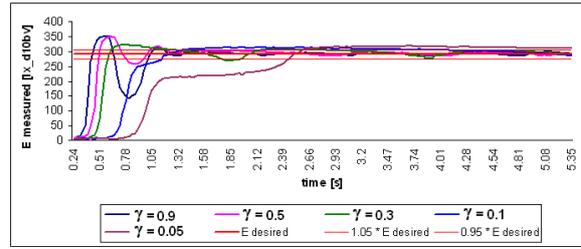
This section presents the experimental results achieved during the tuning process of the CMAC controller (via learning rate modification) and the behavior of the automatic lighting control system (ALCS) in the presence of disturbances.

The performances achieved by the ALCS are imposed by user's human eye perception. For this purpose the overshoot of the system response may have reduced values ( $\leq 5\%$ ) and the steady-state error may have to be in the interval  $[ -0.05 \cdot E_{desired}, 0.05 \cdot E_{desired}]$ .

The desired luminance on the working plane is set to  $290lx_{d10bv}$ . The sampling time is  $T = 29.898ms$ .

The source code which runs on PIC18F4455 controller was written in C and compiled with MPLAB IDE. After the compilation process the resulted hex file was uploaded on PIC18F4455 with PICDEM(TM) FS USB Demo Tool. The data from PIC were acquired using Terminal v1.9b.

Figure 6 shows the step response family when the learning rate is variable. The increase of the learning rate will reduce the transient response time but will increase the overshoot.

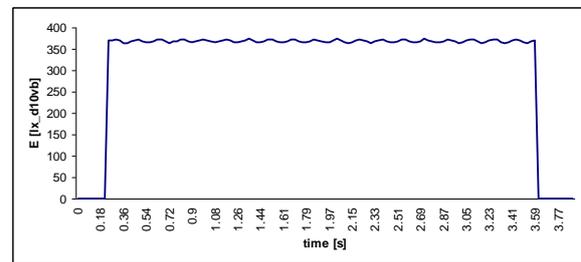


**Fig. 6 - Step response family of the ALCS ( $\gamma=0.05 \div 0.9$ ,  $T=29.898ms$ )**

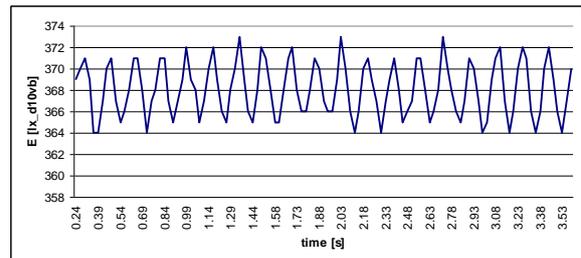
For the sets of learning rate values used in fig.6 we tested the stability of the ALCS when the luminance on the desk surface was disturbed by the additional luminance (electric luminance disturbance) produced by the disturbance desk lamp.

The shape of the electric luminance disturbance is presented in fig. 7 and was achieved by turning the power ON, keeping it a while in this position and then turning power of the disturbance desk lamp to OFF. In this case the disturbance desk lamp is situated near the light sensor. When the desk lamp disturbance is ON and the controlled desk lamp is OFF the luminance on the working plane has its average value around  $368lx_{d10bv}$ . The disturbance luminance presents oscillations in the range  $[364, 373]lx_{d10bv}$  (fig. 8). These oscillations are not perceived by the human user.

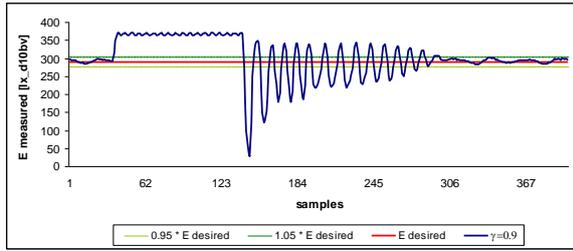
The ALCS is stable, according to fig.9 ÷ fig.13, but after the luminance disturbance disappears, the luminance on the working plane presents attenuated oscillations until it achieves the desired value ( $E_{desired} = 290lx_{d10bv}$ ). The user does not perceive the luminance oscillations in the case of the learning rate  $\gamma=0.05$ . In the other cases the oscillations are perceived by the user and they create visual discomfort.



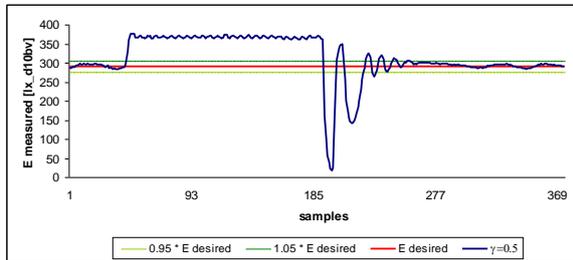
**Fig. 7 – The shape of luminance disturbance**



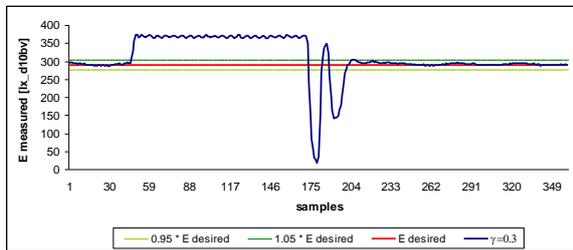
**Fig. 8 – The shape of luminance disturbance (detail from fig. 12)**



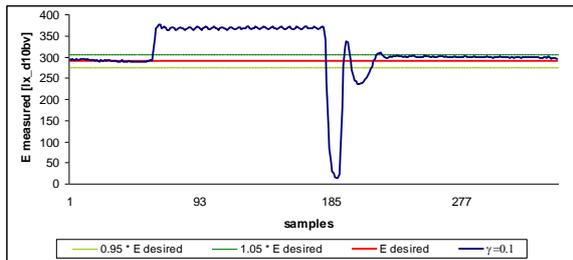
**Fig. 9 – The behavior of the ALCS in the presence of disturbances ( $\gamma=0.9$ )**



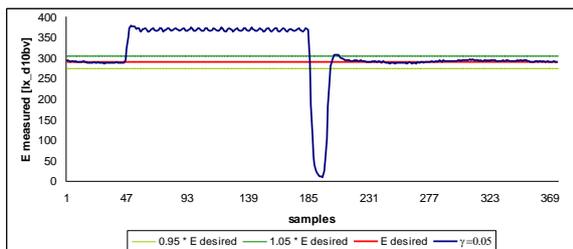
**Fig. 10 – The behavior of the ALCS in the presence of disturbances ( $\gamma=0.5$ )**



**Fig. 11 – The behavior of the ALCS in the presence of disturbances ( $\gamma=0.3$ )**



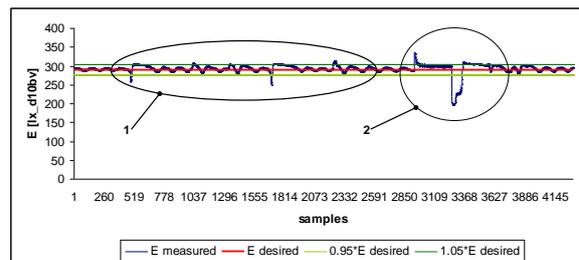
**Fig. 12 – The behavior of the ALCS in the presence of disturbances ( $\gamma=0.1$ )**



**Fig. 13 – The behavior of the ALCS in the presence of disturbances ( $\gamma=0.05$ )**

Following the previous observation for the CMAC controller we chose the learning rate  $\gamma=0.05$  and we studied the behavior of ALCS in the presence

of daylight changes and electric luminance disturbance. The luminance trajectory is presented in fig. 14. The area denoted by 1 represents the behavior of the ALCS in the presence of the daylight changes. The daylight changes were achieved by fast covering a part of the office windows, keeping it covered for a few seconds and fast uncovering the covered part of the office windows. The area denoted by 2 represents the behavior of the ALCS in the presence of the constant daylight contribution and in the presence of the electric luminance disturbance. The shape of the electric luminance disturbance is similar to the one presented in fig. 7 but the amplitude of the signal is smaller (the disturbance desk lamp is situated as in fig. 3, far from the light sensor). According to fig. 14 the ALCS is stable and does not produce visual discomfort for the human user.



**Fig. 14 – The behavior of the ALCS in the presence of disturbances ( $\gamma=0.01$ ): 1) the presence of the daylight disturbances; 2) the presence of the electric luminance disturbance**

For a faster response of the ALCS in the presence of the disturbances, supplementary studies are required. A solution for this situation is the supplementary controller tuning via universe of discourse of the input/output variables of the CMAC controller as those from [4], [5].

## 5. Conclusions

Even though the experimental inverse model is a gross approximation of the process model the ALCS will achieve the imposed performances by the tuning the controller via learning rate. Using the learning rate as the unique tuning parameter the ALCS does not have the possibility to achieve an increased response in the presence of the disturbances without the appearance of the oscillatory behavior which is perceived by the user as a visual discomfort. For this reason the studied ALCS is recommended for office or home applications where the user needs to feel the daylight changes in the light environment.

## References

- [1] Albus, J.S. - *New Approach to Manipulator Control: The Cerebellar Model Articulation Controller (CMAC)*, Transactions of the ASME Journal of Dynamic Systems, Measurement, and Control, September 1975, p. 220 – 227, 1975;
- [2] Brown M., Harris C. - *Neurofuzzy Adaptive Modelling and Control*, Prentice Hall International

(UK) Limited, 1994;

[3] Grif H.S. - *Contribuții privind tehnici de inteligență artificială în conducerea sistemelor de iluminat interior (Contributions regarding artificial intelligence techniques in interior lighting systems control)*. PhD. Thesis, The Technical University Cluj Napoca, Romania, 2006;

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

[5] Grif, H.S., Dulău, M. - *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, p. 17-23, 2011;

[6] Passino, K.M., Yurkovich, S. - *Fuzzy Control*, Addison Wesley Longman, Inc, 1998;

[7] Qin, T., Zhang, H., Chen, Z., and Xiang, W. - *Continuous CMAC-QRLS and Its Systolic Array*, Neural Processing Letters, No. 22, p. 1–16, 2005;

[8] Tham, C.K. - *Modular On-Line Function Approximation for Scaling Up Reinforcement Learning*, University of Cambridge, Cambridge, England, 1994;

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