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Identification of Model Lightening System and Design of PID Controllers for the Purpose of Energy Savings by Using of MATLAB and Their Functionality in LabVIEW

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1. Introduction

Lightning conditions of growing places by cultivation of crops are together with nutritional and consumptive conditions the most important presumptions by creating of plants biomass. Sunshine intensity varies during the day due to the angel of sunrays impact on earth surface what is the result of year season changing. The light intensity is changing during the day also, as a result of weather, clouds, or the natural movement of sun on the sky. For the plants is most useful light with spectral wavelength *400–710 nm* (Photosynthetically Active Radiation PAR). Indoor cultivation areas are significant consumers of electrical energy especially during winter season. Some plant species for the optimal growth needs light energy flow 12–16 hours per day. During the day changes the light intensity. The illumination with constant light flow ensures optimal light conditions but on the other site with big energy costs. One way how to reduce the energy costs is choice of the right type of controller mediated the supplemental lightening according to actual PAR light conditions and PAR necessary for optimal plant growth. For the correct work of controllers important our model systems identify and describe with transfer function. For identification we used "response on unit step" method on the input and LabVIEW program with measuring card for measuring the output of the system.

2. Material and methods

Studied system is composed of semiconductor sensor created from silicone photodiode sensible in shortwave light spectral area. The sensor construction is by using of correction optical filters adapted to the maximum sensitivity of the light spectrum in PAR area (*380–720 nm*). The other part of studied system is supplemental lightening halogen lamp (*U = 24 V, P = 150 W*). Measurement of step response was necessary make from zero conditions what in this example (because of measuring depend on light) means to place the model into dark chambers. Schematic representation of the measurement is in figure 1.

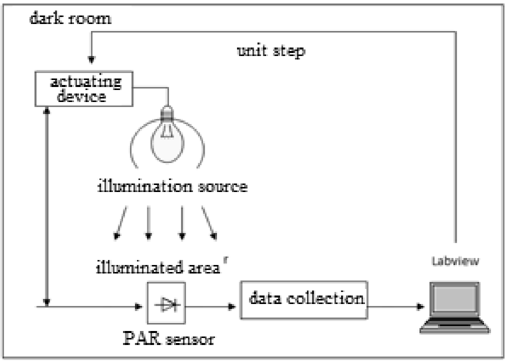
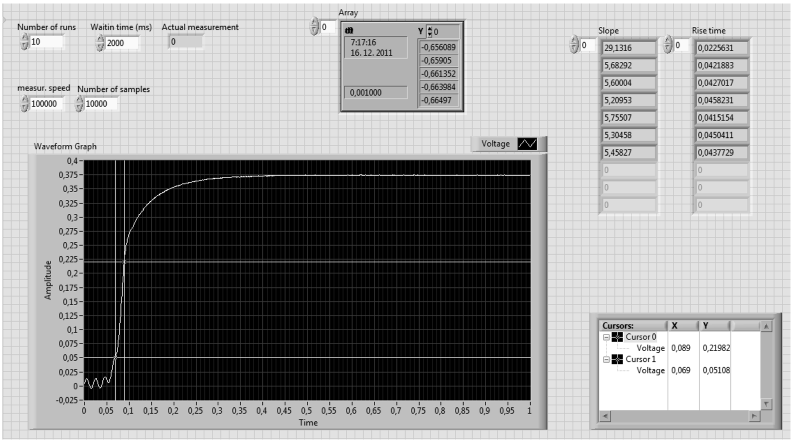


Fig. 1. Scheme of measuring the transient characteristics
Rys. 1. Schemat pomiaru charakterystyki przejściowej

To measure we used LabVIEW program and additional *A/D, D/A I/O* measuring card NI – USB 6211 (*250 ks/s*) that can be directly implemented in the program and it is possible to measure fast events with it. In LabVIEW was created software. On the beginning of measurement starts sampling the input signal and in the same time the software switch on the actuating device (electrical bulb). Measured data are archived into file and are prepared for next processing. In the software is possible to change sampling frequency, number of samples per measurement and numbers of measurements figure 2.



Number of runs: 10
Waitin time (ms): 2000
Actual measurement: 0
measur. speed: 100000
Number of samples: 10000

Array: 0
7:17:16
16. 12. 2011
0,001000
Y: 0
-0,656089
-0,65905
-0,661352
-0,663984
-0,66497

Slope	Rise time
29,1316	0,0225631
5,68292	0,0421883
5,60004	0,0427017
5,20953	0,0458231
5,75507	0,0415154
5,30458	0,0450411
5,45827	0,0437729
0	0
0	0
0	0

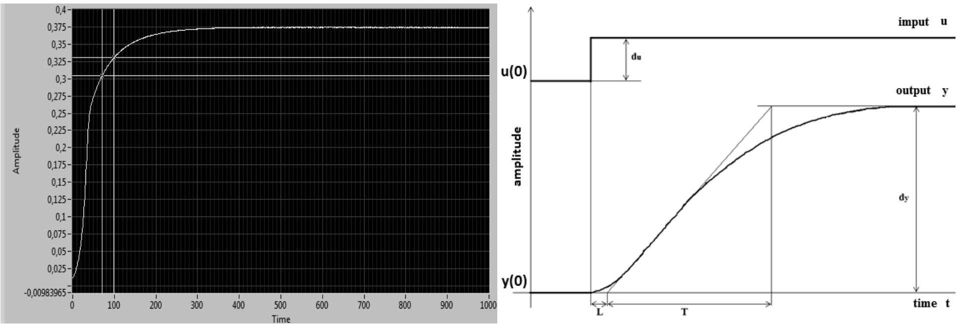
Cursors:	X	Y
Cursor 0		
Voltage	0,089	0,21982
Cursor 1		
Voltage	0,069	0,05108

Fig. 2. Program for measuring the transient response in LabVIEW
Rys. 2. Program do mierzenia charakterystyki przejściowej w LabVIEW

The measurement parameters was set on number of samples for one measurement *n = 1000*. Number of repeats for one measurement *N = 7*. The first measurement started from idle status (it means cold bulb) therefore was different from the others and was excluded from average.

3. Analysis of measured data

The measured data were averaged and analysed using LabVIEW 2011. From the measured values was constructed step response (unit step response for switching on the halogen lamp) Figure 3 a. The figure shows that the unit step response is the shape of *"S"*. For this course we can use an algorithm for processing *"S"* courses (Klán, 2000) design for MALAB program. This algorithm after loading the matrix elements (data from measurement) calculated the time creep *L* (transport delay) and rise time *T* (time constant).



a) b)

Fig. 3. a) Step response of illumination system; b) Response of second order system „*S*“ course

Rys. 3. a) odpowiedź jednostkowego skoku na system oświetlenia; b) odpowiedź drugiego rzędu na przebieg *S*

This type of system we represent in Laplace form as:

$$G_S = \frac{K_S}{(T_1 s + 1).(T_2 s + 1)} \tag{1}$$

Where:

$T_1 = T$
$T_2 = L$

L, *T* and *τ* parameters we calculate with MATLAB with using of this script (Klán,2000):

```
a=["MATICA PRVKOV"];          % load the matrix
l=length(a);                  % find out the matrix length
Ts=0.001;                     % sampling period
Tar=Ts*sum((a(l)-a)/a(l));    % average time of stabiliza-
tion
N=round(Tar/Ts);              % number of samples till sta-
bilization
ya=a(1:N);                    % samples till stabilization
T=Ts*exp(1)*sum(ya/a(l))      % calculation of T constant
L=Tar-T                       % calculation of L constant
Tau=L/Tar                     % normalized traffic delay
```

Then parameters as result from script: ***T = 0,0439***; ***L=0,0066***; ***τ = 0,1301***

Amplification of system K_s we calculate after stabilization of transient:

$$K_S = y_{\max} - y_{\min} = 0{,}374183 - 0 = 0{,}374183 \tag{2}$$

$$G_S = \frac{K_S}{(T_1 s+1).(T_2 s+1)} \quad \Rightarrow \quad G_S = \frac{0{,}374183}{(0{,}0066s+1).(0{,}0439+1)} \tag{3}$$

Transfer of result system (2) we can verify after application of unit step during simulation in MATLAB.

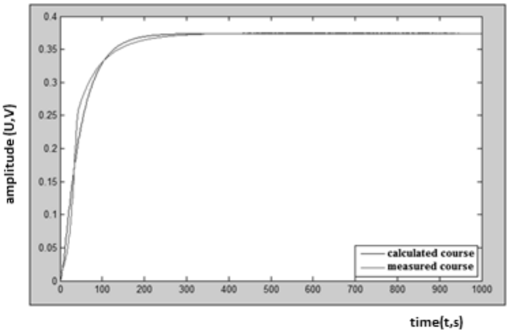


Fig. 4. Measured and real course of system response after unit step application
Rys. 4. Zmierzony i rzeczywisty przebieg reakcji systemu na skok jednostkowy

4. Calculation of PID controller

To adjust the parameters of PI or PID controller we can use several methods, when are known values of *Ks, T, L, τ*, we can set the type of controller.

If the system is identified as a system of second order:

$$G_S = \frac{0{,}374183}{(0{,}0066s+1).(0{,}0439+1)}$$

With step response of „S“ type. We can then determine for amplification K_P = *0,374183* and time constants T_1 = *L* = *0,0066 s*, T_2 = *T* = *0,0439 s*, *τ* = *0,1301* a T_{ar} = *0,0505 s* PID parameters after:

a) Fruehauf and col.

$$K = \frac{5T}{9K_P L} = \frac{5.0{,}0439}{9.0{,}374183.0{,}0066} = \mathit{9{,}875} \tag{4}$$

$$T_I = 5.0{,}0066 = 0{,}033 \tag{5}$$

$$T_D \le 0{,}5.0{,}0066 \le 0{,}0033 \tag{6}$$

b) Aström Hägglund

$$K = 3{,}8\frac{T}{K_P L}\exp(-8{,}4\tau + 7{,}3\tau^2) = 3{,}8\frac{0{,}0439}{0{,}374.0{,}0066}\exp(-8{,}4.0{,}1301 + 7{,}3.0{,}1301^2)$$

$$=\mathit{25{,}62} \tag{7}$$

$$T_I = 5{,}2\exp(-2{,}5.0{,}1301 - 1{,}4.0{,}1301^2) = \mathit{0{,}024} \tag{8}$$

$$T_D = 0{,}89.0{,}0066\exp(-0{,}37.0{,}1301 - 4{,}1.0{,}1301^2) = \mathit{0{,}0052} \tag{9}$$

c) PI Aström Hägglund

$$K = 0{,}29\frac{T}{K_P L}\exp(-2{,}7\tau + 3{,}7\tau^2) = 0{,}29\frac{0{,}0439}{0{,}374.0{,}0066}\exp(-2{,}7.0{,}1301 + 3{,}7.0{,}1301^2)$$

$$=\boldsymbol{3{,}86} \tag{10}$$

$$T_I = 8{,}9\exp(-6{,}6.0{,}1301 + 3{,}0.0{,}1301^2) = \boldsymbol{0{,}026} \tag{11}$$

D parameter for *PID* controller we calculate:

$$T_D \le T_I / 4 = 0{,}026/4 \le \boldsymbol{0{,}0065} \tag{12}$$

Balanced setting

$$K = \frac{1}{K_P}\left[1 - \frac{2\tau}{1+\sqrt{1+2\tau^2}}\right] = \frac{1}{0{,}37}\left[1 - \frac{2.0{,}1301}{1+\sqrt{1+2.0{,}1301^2}}\right] = \mathit{2{,}33} \tag{13}$$

$$T_I = \left[\frac{1+\sqrt{1+2\tau^2}}{2} - \tau\right]T_{ar} = \left[\frac{1+\sqrt{1+20{,}01301^2}}{2} - 0{,}1301\right]0{,}0505 = \mathit{0{,}0443} \tag{14}$$

D parameter for PID controller we calculate:

$$T_D \le T_I / 4 = \mathit{0{,}0443/4} \le \mathit{0{,}01107} \tag{15}$$

Setting after Ziegler-Nicholsa

From measurement on fig. 2 we can determine the duration of one sample $\Delta t = 0{,}001\ s$, the change between two samples $\Delta y = 0{,}011063$ and step change $\Delta u = 1$. Delay parameter of the rising $L = 0{,}0066\ s$.

We determine the steepness:

$$R = \frac{\Delta y}{\Delta t.\Delta u} = \frac{0{,}011063}{0{,}001.1} = 11{,}063 \tag{16}$$

PID parameters we can calculate (Olejár, Hrubý, Lukáč, 2009):

$$K = 1{,}2/R.L = 1{,}2/11{,}063.0{,}0066 = 16{,}44 \tag{17}$$

$$T_I = 2.L = 2.0{,}0066 = 0{,}0132 \tag{18}$$

$$T_D = 0{,}5.L = 0{,}5.0{,}0066 = 0{,}0033 \tag{19}$$

5. Verification of the calculated controllers in MATLAB

After connecting the transmission of system *(GS)* and transmission of controller *(GR)* into the control circuit and calculation of the common transmission in the form *G = GS.GR / (1 + GS.GR)* were applied on the model system Figure 5 unit step and monitor its response in MATLAB simulation Figure 6.

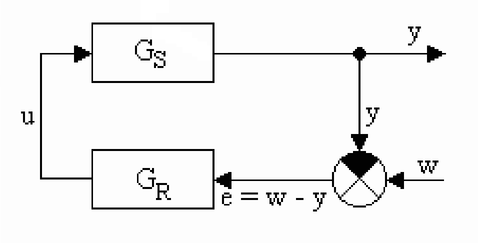


Fig. 5. Connection of the controller and controlled system transmission
Rys. 5. Transfer przeniesienia regulatora i kontrolowanego systemu

After substituting values of *PID* controllers, counting the results of transfer we simulated unit step in MATLAB, we get the behaviour (figure 6) of the system.

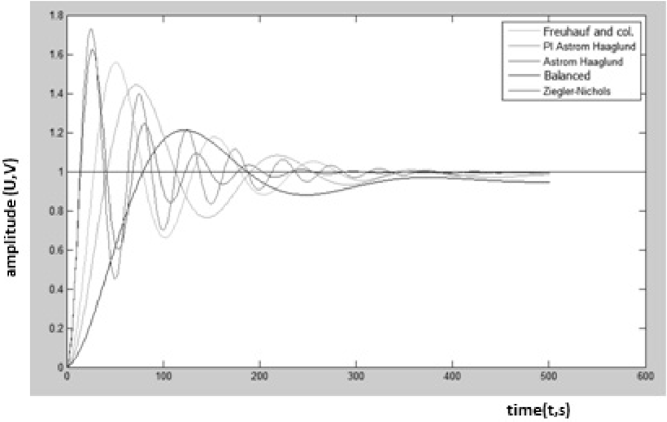


Fig. 6. Curves of calculated *PID* controller as a response to unit step
Rys. 6. Obliczenie krzywej regulatora *PID* na jednostkowy skok.

6. The measuring of calculated PID controllers properties in LabVIEW (tuning of the controllers)

The measurement was done after the inclusion of *PID* controller into the illumination system. The system was designed for tuning of optimal *PID* controllers parameters for illumination in greenhouses. This model system consists of the illumination (simulation) reflector, measuring card design for collecting data, circuits for *PWM* regulation of the additional illumination lamp power. Software was developed in LabVIEW and can directly use a *PID* controller implemented in LabVIEW. The program allows us to adjust the calculated parameters of *PID* controller (Tab. 1) and directly tune the functionality on the model process.

Table 1. Calculated parameters of designed *PID* controllers
Tabela 1. Obliczone parametry zaprojektowanych regulatorów *PID*

PID	Fruehauf and col.	Aström Hägglund	PI Aström Hägglund	Balanced setting	Ziegler - Nichols
K	9,87	25,62	3,98	2,33	16,44
T_I	0,033	0,024	0,026	0,043	0,0132
T_D	≤ 0,0033	0,0052	≤ 0,065	≤ 0,011	0,0033

7. Description of measured system

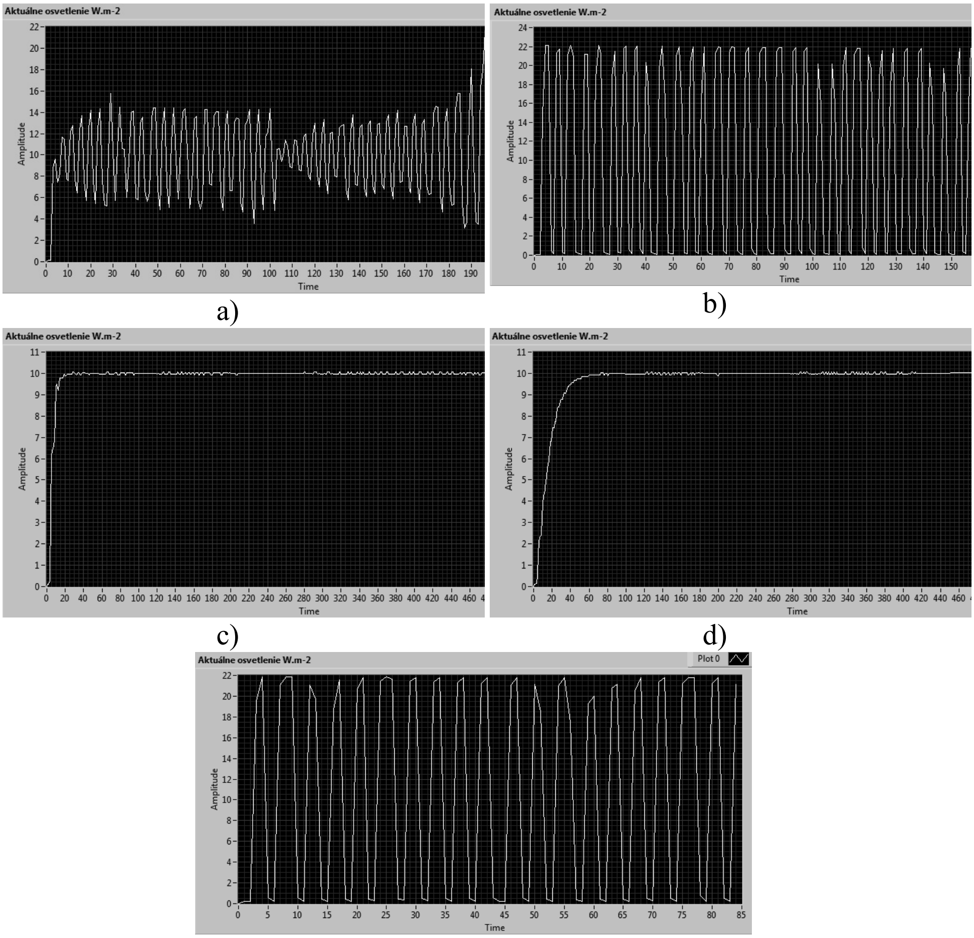
Illumination system model with light source *U = 24V P = 150 W* can generate maximal value of (Photosyntetically Active Radiation) *PAR = 22 W.m-2*. Bulb power control and the PAR control also is through PWM module of microcontroller C8051F340 and USB/UART interface, which communicate with LabVIEW. Control is in range *0–100%* of bulb power. The bulb circuit is switched with MOS FET transistor. Semiconductor illumination sensor is connected to 24bit A/D converter and the conversion result is sent through microcontroller into PC for next processing in LabVIEW. Measurement was made every time for 100 samples and the time of measurement was *100 s*.

8. Measurement of lighting in system and tuning of PID controllers

After entering the calculated constants *K, TI, TD,* into the software controller and setting the requesting value of lighting $FAR = 10\ Wm^{-2}$ in the system, when the illumination in the system reaches the desired value, the calculated controller parameters are suitable for the real process. Otherwise, it is necessary to tune manually the PID constants, so that the regulator during controlling or after start, reach a stable state. On Figure 7 c and d, we can see stabile courses of regulators calculated after balanced method and PI Aström and Hägglund method. In the remaining cases it was necessary parameters of PID controller tune manually during runtime. New parameters we can see in (Tab. 2).

Table 2. Calculated and tuned PID controller parameters
Tabela 2. Obliczone i nastojone parametry regulatora PID

PID	PI Aström Hägglund	Balanced method	Fruehauf and col.	Aström Hägglund	Ziegler - Nichols
K	3,98	2,33	6,575	6,4	6,1
T_I	0,026	0,043	0,033	0,05	0,036
T_D	≤ 0,065	≤ 0,011	≤ 0,0033	0,002	0,004



a) b)

c) d)

e)

Fig. 7. Courses of calculated *PID* controllers with methods: a) Fruehauf and col., b) *PID* Aström Hägglund c) *PI* Aström Hägglund d) Balanced method e) Ziegler-Nichols

Rys. 7. Obliczone przebiegi regulatora *PID* metodami: a) Fruehauf and col., b) *PID* Aström Hägglund c) *PI* Aström Hägglund d) Balanced method e) Ziegler-Nichols

9. Assessment of time regulation and quality control parameters

The regulation time for each controller is time when the controller reaches the zone of insensitivity *$\delta = \pm 5\%$,* which is in this case, the value of intensity $E = 9{,}5\ Wm^{-2}$. I was comparing the time when the controller reaches this zone and stay with the regulated value in it. I made the measurement 10 times for each *PID* controller. The times were averaged. Results of measured and averaged times are in table 3. Quality control parameters are measured by regulating the intensity during outdoor light simulation. We simulated the external illumination (the shape was the same as the course of daily summer sun illumination) and we studied the ability of the regulator to adapt to changes and hold the best possible requested value. In tab. 4 we can see the maximal and minimal value of variable overshoot as well difference between these values. Based on these parameters we consider the suitability of each regulator to control the process.

Table 3. Measured rise times of *PID* controllers
Tabela 3. Zmierzony czas narastania regulatora *PID*

Controller	PI Aström Hägglund	Balanced method	Fruehauf and col.	(PID) Aström Hägglund	Ziegler - Nichols
Rise time (s)	**5,391**	17,045	4,364	**2,622**	5,016

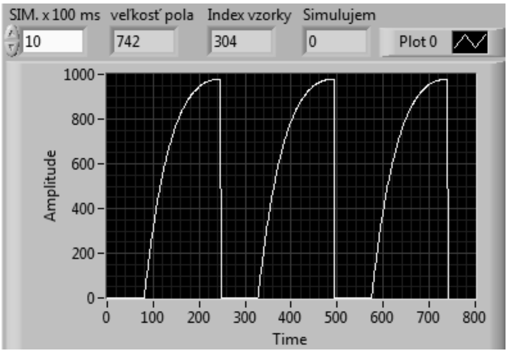
Table 4. Measured values of maximal and minimal overshoot by simulation of day light
Tabela 4. Zmierzone wartościmaksymalnego i minimalnego przeregulowania przy symulacji dziennego oświetlenia

Indicators of the quality of controlled process 1 s	PI Aström Hägglund	Balanced method	Fruehauf and col.	(PID) Aström Hägglund	Ziegler - Nichols
Maximal overshoot - average, $W.m^{-2}$	13,4674	14,1659	13,3398	13,2432	13,4150
Maximal overshoot - average, $W.m^{-2}$	12,5375	11,9164	12,6537	12,7607	12,0639
Diferrence	**0,9299**	2,2495	0,6861	**0,4825**	1,3511

10. Energy consumption comparison of calculated PID controllers

Quality of regulation in terms of energy savings we evaluate on the basis of the percentage of positive action interventions considered in during the process regulation.

To the unnecessary energy consumption occurs especially when the process variable is overshoot (it means is over the requested value) especially when the controller inflexibly react on the changes of controlled value. In other cases (when the value is under the requested) it leads to energy savings (but these are undesired) because the controller does not provide enough requested value in system. This affects decreasing quality of controlled process. We set the simulation for comparing only the overshooting of controlled process. FAR illumination was set on $E = 13\ W.m^{-2}$ and the course of simulated illumination is on figure 8.



SIM. x 100 ms: 10
veľkosť pola: 742
Index vzorky: 304
Simulujem: 0

Fig. 8. The course of simulated illumination in evaluating of energy savings
Rys. 8. Przebieg symulacji oświetlenia w ocenie oszczędności energii

Because regulators in the real process will run continuously switched on, I limited evaluation of results of savings only on the steady states of controlled process. The results are then easier to interpret. The resulting percentage of the controlled output by the requested value $E = 13\ W.m^{-2}$ what represents the *PWM* byte approximately on value $PWM = 181 = 70.98\%$ of the maximum achievable power of bulb we became after counting *PWM* actions of the controller. After counting we make the percent conversion of the result to against continuous illumination during regulation. In table 5 we can see the percentage of power consumption for each *PID* controller.

Table 5. Indicators of energy consumption for *PID* controllers
Tabela 5. Wskaźniki zużycia energii w regulatorach *PID*

Indicators of energy consumption	PI Aström Hägglund	Balanced method	Fruehauf and col.	(PID) Aström Hägglund	Ziegler - Nichols
The percentage of PWM output actions, %	**30,2559**	33,8247	27,4611	**26,5051**	31,1194

11. Conclusion

The parameters of *PID* controllers we calculated by using of mentioned ways and their functionality tested in the MATLAB program. On the figure 6 are courses of systems after unit step MATLAB simulation. The best result reached the *PI* Astrom Hagglund and Balanced controller although they work with permanent control deviation. Remaining controllers reached the steady state too but with a large variable overshoot. This can be the reason of instability by controlling of real process figure 7 a, b, e.

By the controlling of real process the best controller was *PI* Astrom Hagglund and from hand tuned controllers *PID* Astrom Hagglund. Their rising times on requested value is the best from all five controllers table 3. By quality controlling process assessment (variable overshooting) were the best controllers *PI* Astrom Hagglund and *PID* Astrom Hagglund too table 4. Remaining controllers after hand tanning works properly and with their parameters are suitable for controlling investigated process. From the site of energy saving by controlling the process were the also these controllers (*PI* Astrom Hagglund and *PID* Astrom Hagglund) the best. *PID* Astrom Hagglund controller saves more than 7% of energy compared to the balanced method controller.

The difference between theoretically counted values and real instability of controllers by measuring in LabVIEW was caused with the different conception of real *PID* and software *PID* used in LabVIEW. Software *PID* controller does not work on the traditional base and with its implementation into PC it becomes PSD controller. Another problem was the delay of measured signal carrying data from measured process. Cycle time was approximately *437 ms* after which the controller set the output process values. With this delay the controlling process lost its continuity. By decreasing of the cycle time we improve the behaviour of counted controllers and its suitability for controlling investigated process.

References

1. **Olejár M., Hrubý D., Lukáč O.:** *Metódy riadenia mikroklimatických podmienok v uzavretých priestoroch a ich vplyv na úsporu elektrickej energie*. Vydavateľstvo SPU v Nitre, 2009, ISBN 978-80-552-0316-4.
2. **Havlíček J., Vlach J., Vlach M., Vlachová V.:** *Začíname s LabVIEW*. BEN – technická literatúra, 2008, ISBN 978-80-7300-245-9.
3. **Němec Z.:** *Prostředky automatizovaného řízení – elektrické*. Ústav automatizace a informatiky, Brno 2002.
4. **Klán P.:** *Moderní metódy nastavení PID regulátorú*. Časopis AUTOMA 2000, číslo 9.
5. **Olejár M., Hrubý D., Lukáč O., Bystriansky P.:** *Vplyv rôznych regulačných metód na úsporu elektrickej energie*. In *Acta technologica agriculturae*. SPU v Nitre, 2009, ISSN 1335-2555, 2008, roč. 11, č. 2, 49-53.
6. **Veselý V., Drahoš P.:** *Inžinierske metódy nastavovania parametrov regulátorov* (1). ATP juornal 2/2004. Dostupné na internete: http://www.atpjournal.sk/buxus/docs/atp-2004-02-74_77.pdf
7. **GREENHOUSE HORTICULTURE**. 2005. [online] Computer control systems, sensors and monitoring equipemement in greenghouse. Primary Industries Agriculture. Internet source: http://www.dpi.nsw.gov.au/agriculture/horticulture/greenhouse/structures/computer-control
8. **RUNKLE, E.** 2006. [online document]. Daily Light Integral Defined. Technically speaking. Internet source: http://www.hrt.msu.edu/Energy/Notebook/pdf/Sec1/Daily_Light_Integral_Defined_by_Runkle.pdf
9. **DORAIS, M.** 2003. [online document]. The use of supplemental lighting for vegetable crop production: light intensity, crop response, nutrition, crop management, cultural practices. Canadian Greenhouse Conference October 9, 2003. Internet source: http://www.agrireseau.qc.ca/legumesdeserre/Documents/CGC-Dorais200fin2.PDF
10. **LI-COR Biosciences.** [online]. Radiation Measurement Instruments. 2004. Internet source : <http://www.licor.com/env/PDF/RMB.pdf>

Identyfikacja modelu systemu rozjaśniania i zaprojektowania regulatora PID w celu oszczędności energii przy wykorzystaniu programu MATLAB i funkcjonalności LabVIEW

Streszczenie

System sterowany jest częścią pętli i konieczne jest rozważenie go jako osobnej części z konkretnej nieruchomości. Podczas wyboru właściwego regulatora PID ważne jest, aby zrozumieć dynamiczne właściwości kontrolowanego systemu. Na opis tego obiektu zostały opracowane różne metody bilansów energii i następnych modeli matematycznych korygujących przejęcie funkcji transferowych. W praktyce lepiej jest użyć metod, których obserwujemy zachowanie dla konkretnych warunków systemowych (na przykład odpowiedzi na jednostkowy skok na wejściu lub częstotliwość sygnału). Według Behaving wiemy jak matematycznie opisać systemu i następnie wybrać właściwy rodzaj regulatora PID z jego parametrami. Ten artykuł skupia się na identyfikacji systemu oświetlenia dla uprawy roślin szklarniowych oraz prawidłowego zaprojektowania parametrów regulatora PID do sterowania oświetleniem, tak aby zorientowany był on na oszczędności energii.