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Åström, Karl Johan; Zhou, Zhao-Ying

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OF THE SAMPLING PERIOD FOR PROCESSES WITH TIME DELAYS SELF-TUNERS WITH AUTOMATIC ADJUSTMENT

KARL JOHAN ÅSTRÖM ZHOU ZHAO-YING LUND INSTITUTE OF TECHNOLOGY DEPARTMENT OF AUTOMATIC CONTROL AUGUST 1981

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August 1981

Department of Automatic Control Lund Institute of Technology

Karl Johan Åström

OF THE SAMPLING PERIOD FOR PROCESSES WITH TIME DELAYS

SELF-TUNERS WITH AUTOMATIC ADJUSTMENT

Zhou Zhao-ying

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ABSIRACT

Simple self-tuners for processes with time delay and low order dynamics are developed. Methods for automatic adjustment of the sampling period are discussed. The performance of the regulators are illustrated by simulation; and experiments on laboratory processes.

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ш Self-tuner with Two More Extra Parameters of

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1. INTRODUCTION

å lag with is much shorter than T Cian Cian dynamics order a first whose Sassacoud and a If the time delay T a time delay T many industrial with a time delv time constant T_{*} There are approximated

regulator delay π has the process time proportional If the T then can for example be used. ∢ σ than the time constant easy to control. gain ام. is larger a high process with the υ

low frequencies. very already for shift considerable phase

when value of the process gain. To control such processes in a reasonable way it is necessary to have controllers with dead time compensation e.g. of the type proposed by Smith (1958). Dead time compensation in essence amounts to storing past 0 V This means the inverse is possible chosen account ů D - ene than ۲. ۲ controller must then than into signal. In this way 1655 op gain is less gain has to be le them in essence taking th to maintain a high loop gain. proportional loop the control and The gain of a proport small that the total that the proportional actions determining control

and The problem formulation is given in section 2. The design parameter sampling from simulations processes stated are given in section 6. the with the to control ų H problem tor system. solved in section 3. Section 4 deals estimation problem. Different ways of adjusting period are covered in section 5. Results from deriod are covered in Section 5. Results from oeriod are covered in Section 5. Results from computer merus ustriy on an analog problem tu. simulated

2. THE CONTROL PROBLEM

4 this section. The for the regulator formulation φ that the i D and inherent discussed the same N m N then characterized freedom structure which the pesodoud . L . L avoid given. package PPCP formulation regulator structure chosen ų. **p** ار. 1 L little problem a re R2⁻in the DDC pack Nordic laboratory. : one-degree-of-controlled are problem ŋ be modified control The the the D D

<u>Regulator</u> Structure

The regulator R2 is characterized by

e(t-h) ú. ł e(t) Ó ψī L H $\nabla u (t-2h)$ r.N + ∇u(t-h) -يء + $\nabla u(t)$

where u(t) is the control signal and

e(t) = u(t) - y(t)

2 to Harowitz always introduce 10 regulator . 小 This operator. The according function. the regulator will controller transfer a difference the one-degree-of-freedom in of this °° ∕ the error, and ∇ Because ມ I H Ν (1963). 20 h0 Π . ال <u>الا.</u> đ

unnecessarily regulator Ч К **characterized** the it may result in an replace configuration ţ useful freedom thus serious limitation because .H ቴ Ħ degree overshoot. two n) large th th i S

$$\nabla u(t) + r \nabla u(t-h) + r \nabla u(t-2h) = t u (t) + t t u (t-h) 0 c 0 1 c - 5 y(t) - 5 y(t-h) (2.1) - 5 y(t) - 5 y(t-h) (2.1) - 5 y(t-h) (2.1) 0 - 5 y(t) - 5 y(t-h) (2.1) - 5 y($$

the and This the because 4 via increase system. modification ų. the This part of introduced algorithm is incremental. drastic in the analog a 70 without actions changed functions control ů D cont rol computer not decrease system. The Can

Process_Model

Such 4 Ø. for the purpose is thus ψ N order lag. desc ribed first もての Ū, an approximation is sufficiently accurate control in many cases. The process model ų and cont rolled υ delay ů, time t q U) ÷ processes combination The

$$\frac{dy(t)}{dt} = -\alpha y(t) + \beta u(t-T)$$
(2.2)

The corresponding transfer function is

$$G(s) = -\frac{k}{1+sT} e^{-sT}d$$
 (2.3)

where k =

$$k = \beta / \alpha$$

$$T = 1 / \alpha$$
(2.4)

sampling period sampled with the ທ p rocess the that Assume

9.9 ų es which a described times be des system at t tants can t the sampled syst sampling instants behaviour of ized to the synchronized the equation The ų.

$$y(t) = ay(t-h) + b u(t-kh) + b u(t-kh-h)$$
 (2.5)
1 2

where

$$a = e^{-\alpha h}$$

$$b_{1} = \frac{\beta}{\alpha} [1 - e^{-\alpha (h - T \mod h)}]$$

$$b_{2} = \frac{\beta}{\alpha} [e^{-\alpha (h - T \mod h)} - e^{-\alpha h}]$$

$$k = 1 + T \operatorname{div} h$$

$$(2.6)$$

corresponding is given by the given system اب. time model (2.5) continous the sampled parameters of the ¥ H

$$\alpha = -\frac{1}{h} \ln a$$

$$\beta = -\frac{1}{h(1-a)} \ln a$$

$$\beta = -\frac{1}{h(1-a)} \ln a$$

$$T_{d} = E k -1 - \frac{\ln(ab_{1}+b_{2})/(ab_{1}+ab_{2})}{\ln a}$$
(2.7)

given by gain K and the time constant is b The process H

$$K = \frac{b_1 + b_2}{1 - a}$$

$$T = -h / \ln a$$
(2.8)

 \mathbf{r}

Problem_Formulation

given by an optimization criterion like minimum variance but for many other applications the goal is more loosely defined e.g. to obtain control loops with reasonable gain and settling times. In the applications considered it is also desirable to have are also t t include structure circumstances. decided with a **t** cases there therefore de the observer and with 4 regulator wi der a variety (be captured by time the applications with reasonable gain and the applications considered it is also responses without overshoot. In some ca problems with disturbances. It is the design for a specified settling tim filtering by specifying a first order ob 0 Q under Щ, Can s intended to design which will work well of the applications ca constant. 40 It is (2.1) w Some of time

3. CONTROL DESIGN

The ۱Ü. pole placement settling time ät ÷ 20192 solved. strict, has 0 Q very sampled system NOU for Щ problem can be captured by the specifications call not problem will 9. P they the design since that system and to require overshoot at of the Since and control the origin reasonable essence design. without The

 $z_1 = \exp(-h/T)$

the has Similarly 쁥 that requiring settling time. 5 specified specified at t and ارا. the origin polynomial the ₩ at observer U H where Zeros

z_ = exp (-h/T_) 2_

thus Ŵ command regulator i ار. the desired performance The from **'**0 and T function U F two parameters transfer u V given The specified... ائر. اس the the output controlled by the so that <u>ارا</u> 40 0 designed -signal where

$$H_{d}(z) = \frac{1}{b_{1} + b_{2}} = \frac{1}{z^{k}(z+p_{1})}$$
(3.1)

.

where

 $p_1 = - \exp(-h/T)$

There . р / N. م ۱ H Ν at 2670 ų have thus regulator will The

4 1 1 least two sampling periods. This process. attemped function the å D transfer in Can the delay ÷ obtain the damped ÷ å t because is well ţ ÷ 20 LO be a delay avoided process Line process zeros cancel the ric 0 Q also can not will

 \sim

. separately considered ů D rel rel Ч. (3.2) and (3.1) The

No.Cancellation_of_Process_Zeros

ີເວີ 9 model process sampled the notation z-transform Using

Ъ. described $\frac{B(z)}{A(z)}$ IF H(z) can be

where

 \sim rt) N. L מ м ÷ Ч, ч Ч D H R A(z) 8(≤)

They 5 $\hat{}$ σ F . considered ~ 5 and are τ F ہ ع N II ×. ÷ and situations l ¥. 100 Cases the two represent Only

(2.1) is design U structure the basi . ال respectively. Since the desired regulator such that it contains an integrator synthesis pole placement \sim N T N the -a)(z-1)(z for equation

+

~

$$(z-a)(z-1)(z^{+}r_{1}z^{+}r_{2}) + (b_{1}z^{+}b_{2})(s_{2}z^{+}s_{1}) = z^{2}(z+p_{1}(z+p_{1})(z+p_{1})(z+p_{1})(z+p_{2})(z+2) + (b_{1}z^{+}b_{2})(z+2) + (b_{1}z^{+}b_{2})(s_{2}z^{+}s_{1}) + (b_{1}z^{+}b_{2})(s_{2}z^{+}s_{1}) + (b_{1}z^{+}b_{2})(z+2) + (b_{1}z^{+}b_{2}$$

that origin and ų a e origin poles a the is at the additional pole two ∂ observer н 1997 system has ll X for 940 900 1000 that د 0 s means closed Ň l × This the c 70 °

following the N ų. O powers N of equal for k = 2 obtained coefficients are equations 3 Equating

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can be solved equations linear -N. 4 N. set This

and 0 # N a + -Ω ц. 191 ហ -0 aD

solution The 8 # N D. + $\boldsymbol{\psi} \boldsymbol{\theta}$

$$r_{1} = 1 + a + p_{1} + t_{1} \\
 r_{2} = \{ b_{2}^{2} [(p_{1} + a) + (1+a)r_{1} + (1+a)(p_{1} + a)] + b_{1} b_{2} a r_{1} \rangle / N \\
 s_{0} = \{ b_{2}^{2} [(1+a+a^{2})r_{1} + (1+a)(p_{1} + a)] + N \\
 + b_{2}^{2} [a(1+a)r_{1} + a(p_{1} + a)] - N \\
 + b_{2}^{2} [a(1+a)r_{1} - a(p_{1} + a)] - a^{2} b_{1} r_{1} \rangle / N \\
 t_{0} = (1+p_{1}) / (b_{1} + b_{2}) \\
 N = (b_{1} + b_{2})(ab_{1} + b_{2}) \\
 For k = 1 we have similarly \\
 s_{0} = \frac{1}{1-a} \left[\frac{(1+p_{1})(1+t_{1})}{b_{1} + b_{2}} - \frac{a(a+p_{1})(a+t_{1})}{b_{1} + b_{2}} \right] \\
 s_{1} = \frac{1}{1-a} \left[\frac{a(a+p_{1})(a+t_{1})}{a_{1} + b_{2}} - \frac{a(1+p_{1})(1+t_{1})}{b_{1} + b_{2}} \right] \\
 and$$
(3.6)

E E

 $b_1 + b_2 = 0$ The condition

Which z = 1, åt a zero the process model has implies that

(3.6)

cancels the zero in the regulator. To obtain the controller in that case the factor (z-1) in (3.3) should be cancelled before the polynomials R and S are determined. If this is done the regulator will, however, no longer contain an integrator. This means that if (3.6) holds then there is no regulator of the form (2.1) which will do the Job.

factor in the process model. (2.7) implies that there is a common $ab_1 + b_2 = 0$ The condition

equation This factor should then be cancelled before the equation (3.3) is solved. If (3.7) holds the process model reduced to ົ້

$$H(z) = \frac{1}{z}k$$

õ

.9a) and s in 2 (3.8a) (3.8b) (3.9b) gives ŋ of z in (3.8a) r.N Ø H H coefficients ъ for k = for k the control law are thus equal to zero. Equating coefficients of equal powers = (z+p)(z+t)t t $= (z+p_1)(z+t_1)$ the reduces ٦ م - p₁t) / (2*2) The Process Zero is Cancelled design equation (3.3) **_** р 1 1 In the particular case zb s 1 0 + 1 0 1 цщ Ц o_u(t-kh) 1 $= (p_1 + t_1 + 1)$ П have ~ + ч ά^π ₽ 1° ۲ ۲ ۳ Ψ $(z-1)(z+r) + \frac{1}{1}$ רי ב + **^**# II (3.8b) we т. Т + ~~ , i **–** (z-1)(z+r -1 a + ي ج a. L H H -۶., 1 y(t) . 0^{""} °, ų – **uni** -Hence From N 5... <u>بي</u> The

(3.10a) N 11 H for k for k $= z(z+p_1)(z+t_1)$ $= (z+b_2/b_1)(z+r_1^3)$ The design equation then becomes + $r_1 z$ + r_2 . Hence $z^{2} + r_{1}z + r_{2}$

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Zero

the process

4

NN

(3.10b) $(z-a)(z-1) + b(s_z + s) = (z+p)(z+t)$ 1 0 1 1 1

in (3.10a) gives N Equating coefficients of equal powers of

the solution This linear equation has

-

$$\begin{bmatrix}
r_{1} = p_{1} + t_{1} + a + 1 \\
s_{1} = f(1+a)r_{1} - a + t_{1}p_{1} / b_{1} \\
s_{2} = f(1+a)r_{1} - a + t_{1}p_{1} / b_{1} \\
s_{3} = -ar_{1} / b_{1}
\end{bmatrix}$$
(3.11a)

The remaining parameters of the regulator are then given by

$$r_{1} = -b_{2} / b_{1} + r_{1}'$$

$$r_{2} = r_{1}' b_{2} / b_{1}$$
For k = 1 we have
$$r_{1} = b / b_{1}$$

$$r_{2} = 0$$

$$r_{2} = (1 + a + t_{1} + p_{1}) / b_{1}$$

$$s_{1} = (t_{1} p_{1} - a) / b_{1}$$

$$(3.11b)$$

Regulator_Design_for_B_Polynomials_of_higher_order

the \odot (3.12) ۳ When the sampling period h is smaller than time delay in the estimated model e(t) Д ÷ the degree of polynomial A(z)y(t) = B(z)u(t). 4+ 1 - inf

10 10 10 10 the r. As of B to hand o us a polynomial B of high order. a process with two extra terms of Yew the safe is unknown problem is to we consider a delay time example v follows. the control Ξŧ

$$y(t) = a \ y(t-h) + b_u(t-h) + b_u(t-2h) + b_u(t-2h) + b_d(t-4h) \quad (3.14) + b_d(t-4h) \quad (3.14)$$

The linear regulator is given by
$$R(z)u(t) = T(z) y_r(t) - S(z)y(t) \quad (3.15) + (2)u(t) = T(z) + (1-2)u(t) - S(z)y(t) \quad (3.15) + (2)u(t) = T(z) + (1-2)u(t) - S(z)y(t) \quad (3.15) + (1-2)u(t) + (1-2)u(t) - S(z)y(t) \quad (1-2)u(t) + (1-2)u(t) - S(z)y(t) \quad (1-2)u(t) + (1-2)u(t) - S(z)u(t) \quad (3.16) + (1-2)u(t) + (1-2)u(t) - S(z)u(t) + (1-2)u(t) - S(z)u(t) + (1-2)u(t) - S(z)u(t) + S(z)U(z) = P(z)T_z(z) \quad (3.16)$$

 $A(z)\nabla R(z) + B(z)S(z) = P(z)T(z)$ 1 and

can be (3.16) equating coefficients with same power of z rewritten as a parameter equation

(3.17) When there is no cancellation (3.17) has the form D8 = C

becomes F 17) Ŋ then tor Ĺ 4 202 Щ . Г there 4

$$\mathbf{H} = \begin{bmatrix} \mathbf{r} & \mathbf{r} \\ \mathbf{r} & \mathbf{r} \end{bmatrix} \mathbf{T}$$

$$C = [t_1 + p_1 + 1 + t_1 p_1 0]^T$$

The control signal is given by
$$u(t) = t_0 yr(t) + t_0 t_1 y(t-h) - s_0 y(t) - s_1 y(t-h)$$
$$+ (1-r_1)u(t-h) + (r_1 - r_2)u(t-2h) + (r_2 - r_3)u(t-3h) + r_3 u(t-4h)$$

The test value
$$T = eps (b_0)^4$$
$$com max$$

is used to determine whether there is a common factor.

4. PARAMETER ESTIMATION

pasn extra model ān automatically The also estimated. period : the sampling polynomial B is adjust the 4 parameter (is thue P

(4.1) b_u(t-2) 3 + b_u(t-1) 2 + b_u(t) 1 + = ay(t) y(t+1)

٦ ۲ introduced ŗ. period ۍ. ۱ the sampling notation m u(t-3) the following ų Ņ u (t-2) is chosen u(t-1) the algorithm time unit E y(t-1)the R describe φ(t) where

 $B(t) = [\hat{a}(t) \hat{b}(t) \hat{b}(t) \hat{b}(t) \hat{b}(t)]^{T}$

<u>اب</u> of the parameters estimate sauenbs least The recursive then given by

(4.2) ~ ~ m (t+1)P(t) $P(t)\phi(t+1)R^{-1}(t+1)\phi^{T}$ P(t+1)φ^T(t+1)ε(t+1) the forgetting factor T(t+1) φ(t+1)B(t) + φ(t+1)P(t)φ I L + P(t) = y(t+1)0(t) L. 11 ~ lł . U II $\Theta(t+1)$ P(t+1) ∈(t+1) R(t) where λ

a re the the improve estimated neighbourhood t t not rsed t M is also 0 process between A filter of the measurement estimation. bias signals the ÷ differences t t ÷ Because provided quality

(4.3) y(t) + u(t) + t_1 yf(t-1) بر ۱۱ N yf(t) uf(t)

uf(t-1)-uf(t-2) are repleced by [yf(t-2)-yf(t-1) $\varphi(t)$ and $\varepsilon(t)$ H φ(t)

(4.4) m uf(t-2)-uf(t-3) uf(t-3)-uf(t-4)

4 also been tested it a c $\phi(t) \oplus (t-1)$ variable method yf(t-1) avoid the bias problem. instrumental yf(t) -11 £(t) An

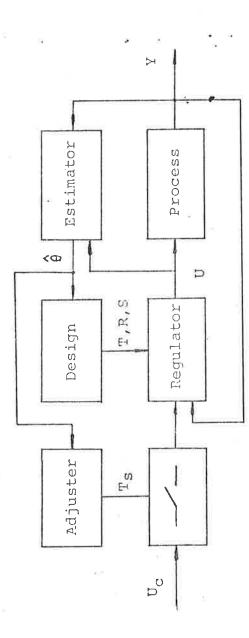
5. ADJUSTING THE SAMPLING PERIOD

parameter. It is Iy. The principles section. A block <u>ان</u> result cussed in this section. (with automatic adjustment in Fig.1. A simulation re automatically. critical discussed in ф, £ . N ц Н to adjust self-tuner 2 shown period are ų. sampling p desirable 2 period Fig.2. adjusting of the sampling ц Х diagram clearly The given for

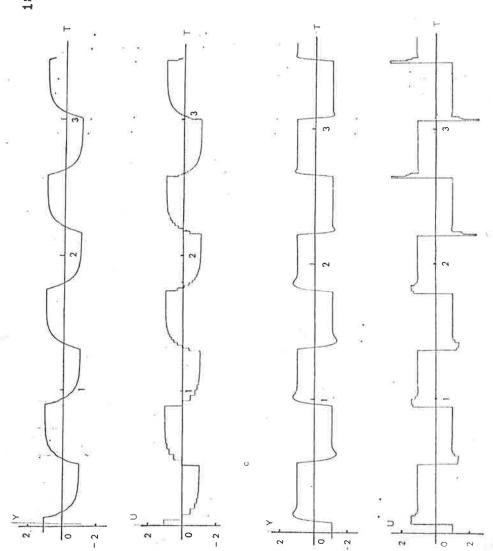
The Case of Known Parameters

the σ the sampling (5.1) H delay obtain (2.3) the time the thus model period 2610 Na Na the than . Ń sampling from 1 smaller 2 0 τ F based than different the should be be larger Ŵ choosing ÷ 22 ц. Н regulator 2 л^о 0 for interval parameter a 1 \sim Ø £ should ru1 \sim the following sampling 0.U If the period Since

the too 0 D between hot should ratio the ---constant pasn Ŵ ÷. ۵ م reasonable condition time should the regulator R2 υ and σ F delay σ α the a de small time ¥ H



adjustment automatic with self-tuner ıŋ, ÷ <u>Eig_1</u>. Structure o of sampling period.



Π. sampling period by The ំ ហ 0.6 sampling exp(-0.4s)/(s+1). t t then the 1.2, 4-0 2.4 to adjustment Process (from self-tuner. adjusted Automatic .u Fig._2. simple period i

- ហុ 0 11 ۵. pole Desired ď
- D II a. pole Desired , m

some (5.2) adjustment 92 2 ţ, automatic better ų. for ÷. Some methods satisfied not method. ų. equality F design 0.2 this $\hat{}$ ۳ other of the ц. Н

below

given

a re

sampling period

the

<u>Automatic.Adjustment</u>

5 reasonable (2.3) for basis ¢ n) period. ut) N (5.1) sampling inequality the the of 9 9 9 9 adjustment с thus natural automatic choice is ц, 11

υ <⊢ 0.75 11 2

the the not ÷ produced ÷ provide suitable value ů ů are is, can ine a suita estimates (2.7)* It delay to determine time .f good apriori estimated from the ÷ straightforward | period. If goo estimate reliable sampling pe time delay thus rt) មា ក ц. Н

can be

however,

<u>00</u>

.mate of h is far from the true value. To see the impulse response of the system and let 2. ... } be the pulse response. It follows ц. H delay time delay value. To a good estimate of far from the true provide a entirely trivial to f the initial estimate 0 Q 1, 3 6 let H чн ب ع ب this

that

J ÖL

$$b_{0} = 0$$

$$b_{0} = b_{1} = 0$$

$$b_{0} = b_{1} = b_{2} = 0$$

$$if h \langle = T_{d} / 3$$

$$b_{0} = b_{1} = b_{2} = 0$$

$$if h \langle = T_{d} / 3$$

ار. from the parameters the the asymptotically delay. ÷ In that case period be estimated time value cases can be distinguished. the sampling estimate the the estimates of be zero if the initial 9.1 P sampling period h is smaller than T / 3. d Can estimates delay 40 to time value used that savenps different / 3 the if the initial it follows b₃ will all can not be least ΰ Several F larger than b₂ and the consistent estimates However, . Since (2*7) ь**1**,

Case 1:
$$| b_1 \rangle \propto \max(| b_2 \rangle | b_3 \rangle$$

 $1n (b_2 + ab_1) / (b_1 + b_2)$
 $T_d = - \frac{1n (b_2 + ab_1) / (b_1 + b_2)}{1n a} h$
(5.5)
Case 2: $| b_1 | \langle \propto \max(| b_2 | | b_1 |)$

$$T_{d} = [1 - \frac{1}{2} + \frac{ab_{2}}{ab_{2}}) / (b_{2} + b_{3})$$

$$T_{d} = [1 - \frac{ab_{2}}{ab_{2}} + \frac{b_{2}}{ab_{3}} + \frac{b_{3}}{ab_{3}} + \frac{b_{3}}{ab$$

 \sim

time the small a v A ъ and ,D parameters all **ц**. н ñ Case

increase stimate k **0** estimate easy t t ÷ apriori ي. ابر ال امر: Neither possibility ā variable ц. Н estimated. mated parameters. available the vari test quantities. One easily estimated ين ۲ n D the DC-gain not number of 045 find good delay the 4. 0

$$b_1 + b_2 + b_3$$

k(1-a)

too Ŵ 0 Q ٠Ħ A third possibility ار. will sampling interval ъ and 1 1 2 . the parameters М ~ ц. •el τ F \sim observation that if h estimated to test the be used the then use small could ţ

the the period of the limit cycle will be between A determination of the frequency of the limit cycle which analysis signal and large ar control function a limit very the describing process gain will than be v system will be unstable. If the system will then have a simple ∢ be detected. es that the p 'υ F The loop Þ bounded cycle will indicates and b small. could H ហ Ň

The automatic follows uð N **'**ש procedure can then be summed up provide an estimate of T thus adjustment

F \sim 2 sampling period large . Choose a sufficient Step_1

~

N υ S self-tuner based Run the

ВС 11 Ą

ЦЦ Ш Ш + AR

-

the Use determine 'n ť converged. dete extra parameter have len the parameters have from estimates with an When the (5.6). <u>Step_2</u>. Wr time delay د 0 (5.5)

រោ F 9 2 Adjust a) mi Step.

Ъ \vdash ø H 10 F

0 Ψ, , В(h) adjustment, update constant. Before the according to (2.6) n) ហ ÷ 8 where \sim ê(T

where Ē f F --Ŵ ► لسا range admissible in an ---Keep . 41 Step.

constant υ ΰ F F N 8^{(N} ×۳ 8 and II II. ۍ ۲ \$**1** γŢ ⊢ н

.

<u>Automatic_Adlustment_2</u>

ų. Can The Ψ he time delay and the adjustment or half the sampling period. -infl strict too is not period to compute the time to double or half sampling given by of the the choice ٦. ال arranged unnecessary procedure 4 0 Q

.

N.

>

F

sampling period h >

sufficient large

<u>Step_1</u>. Choose a

different models τ and 5/2 2 period period two estimated with sampling are estimated with sampling υ **---**40 ч D Step_2. Determination of the range Run a self-tuner with estiomation then 2Td When h > +-1 μ 11 о В ສ ທຸ ٦ Case 1. -A and B 2 1 1 1 1 1 1 1 and B + II ب. ۲ >_N A 1 R ۹. where đ ď

and and $1_{h/2} = b_3(h/2)$ b1 (h/2) p³ (۲) р³(н) 61 (H) H 11 3_{h/2}= then H با ۳ ۳ ц Ч , b₂, b₃ м д ۵ м Д min E b_1 , b_2 , b_3 = h/2 then ч х ۲₀ р. Р ε b₁, b₂, į, Ъ1, ų م ь, 1 Ŵ When 2T_d min E b₁, I F U Choose \vdash \vdash ب ш Keep When min min min 1 18 N М Case Case

2h. H Choose T =

ů D decision -**Dase** will ц period rt) 5 times IA 0.⊤ t t sampling consequtive á(h) period adjustment update increasing the sampling 2 repeats n the Dase Adjusting د 0 Before the decreasing يد 0 If case Step_3. given. 4

for very smooth The formulae squares model 0 Q calculated. A 0(h/2) has been estimated the adjustment will least 0 Q nt) Å B(2h) must Consider follows. value sampling period h the given as case 2 Ч . ال

(5.7) ui N is given period 2h for sampling (H)B(H)φ = the model Then Х

(5.8) f(θ(h), ∇u) + = φ(2h)Θ(2h) Х

proof given in a period The formula is straight forward but tedious. It is Let it suffice here to show the formula se only. Consider the process with sampling 2h. It. signal in tedious. variation of control is the special case h elsewhere. (5.8) ٦D where ÷

b_u(t-k+1) 2 + o_u(t-k+2) 1 ۵ += -ay(t+1)y (t+2)

we have q ۲ For 2h >

Vφ(h)C(h) + φ(2h)8(2h) $\| \cdot \|_{L^2}$ y(t+2)

where

results u(t-1)-u(t-2)F b (2h) u (t-2) cases. 0. It = 1, b₂= b (2h) 1 different m c2 (h) = [u(t+1)-u(t)]u(t) (1-a) -y(t)[a(2h) 4 CHD × several i.e. ۳ ۳ Ъ, р 1 0 U ليا w H H Ш II 1). $T_{d} = 0$, H 11 H (2h) <mark>ь</mark>2 (2h) c₁ (2h) (2h) φ(2h) Consider 8(2h) (H) φV C(H) р Т m

0

1

c₂(2h)

in

m1

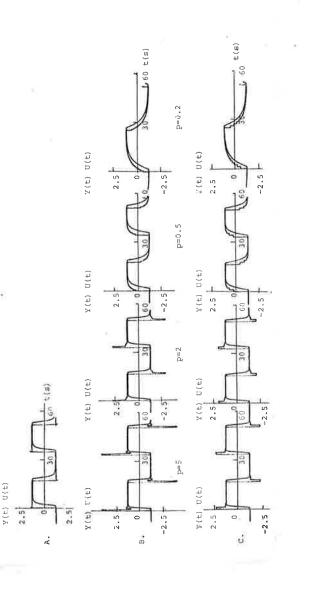
then and $b_2 = 0$. then We have л Д , N ч<mark>о</mark> 11 т Д -÷ N Ľ. 'n in a **.** H I ÷. × + × ł ÷ --ab 2 -ab 2 -ab₁ -ab 1 ů, i.e. i .e. -ab 1 -ab 3). 2h > T_d> h, ۲N M N_a, . <mark>-</mark> **1** <u>д</u> N 0 Ø, 0 I 4). h = T_d, : •°P 11 11 [] H H 11 U 11 11 lt H H II II a (2h) b₁(2h) a (2h) b₁(2h) c₂ (2h) a (2h) b₁(2h) b₂(2h) c₁ (2h) c_2 (2h) c₁ (2h) c₁ (2h) ь₂ (2h) b₂ (2h) c₂ (2h) 2). h >

6. SIMULATION AND EXPERIMENTS

and i n simulations computer written ц С program analog shown もも interactive .iu 1 ç self-tuner by experiments a D the using and 40 The behaviour (using SIMNON a) DEC LSI 11/03 11/03 . Pascal

<u>Changing_time_constant</u>

with **t**0 reacts shows desi red according Fig.3 and self-tuner the control T of th process. ч. D well the very without constant the Mor adjusted 40 illustrate constants time p rocess 1/p. n D The neo I experiments time n) F control. system where ÷ the behaviour in. requirements, self-tuning 1000 changes first closed The the t t



β system 1000 closed U) ÷ constant time Changing <u>Eig_3</u>. Cha self-tuner.

Process exp(-0.9s)/(s+1).

A. without control.

10 ψī. ア . Ö, li 2 â different self-tuner with , m

ų, N . . ${\bf T} = {\bf I}$ H 2 â different with self-tuner . C

Initial_Conditions

the the initial . reasonable Zero and limits reasonable 5 set also its a re Fig.4. If however reach estimates transient will Ш. Н drastically. See an the transient i ÷ values 2 initial given signals changes a re all cont rol output values When

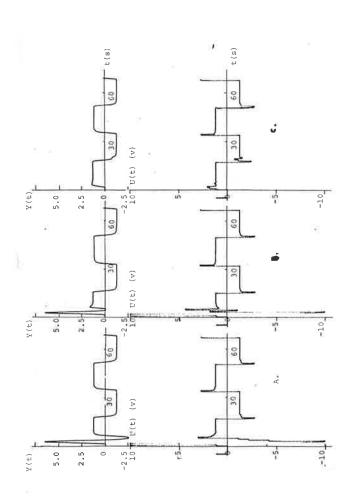
Load_change

Fig.5 changes. disturbances. load e large load dis self-tuner under can tolerate nt) the performance of self-tuner shows The

<u>Automatic_adjustment_of_sampling_period</u>

σ The \sim с. Fig.5. 900 90 shown in Fig.6. in and illustrated e h > T _ a ΰ is il case a °e Ň thm 1 both algorithm algorithm in place for ų. takes results performance adjustment Similar The

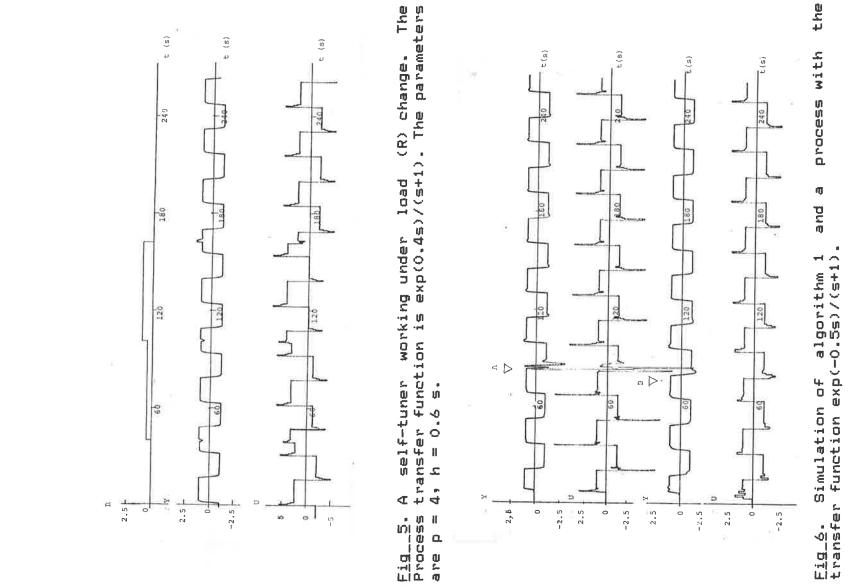
High_order_process_dynamics



1000 initial closed different desi red from exp(0.95)/(s+1); starts self-tuner Process N. . <u>Fig.4</u>. A conditions. H a. system

s. 0.01 11 M D N N D H **1** -0.5, 11 17 . Щ p, 0=0.01 ď

.14. 0 11 мд .33, 0 11 0.01, 52 11 **1** -0-0-П ۳Ø, ċ

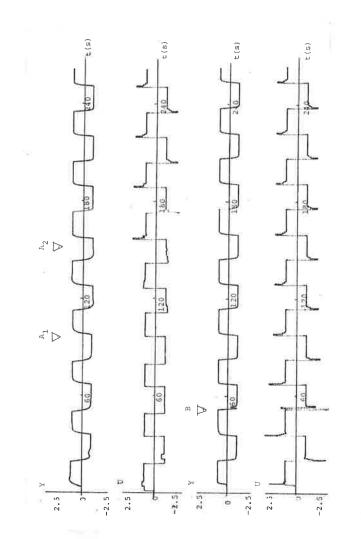


<u>Eig_6.</u> S transfer

from automatically adjusted 10 1-1-1 **ທ**່ The sampling period to 0.76 s. after 70 : Å. ຸ, ທ 0.35

automatically adjusted ų. sampling period s. after 60 s. 0.6 The B. to 8 Û) 1.10

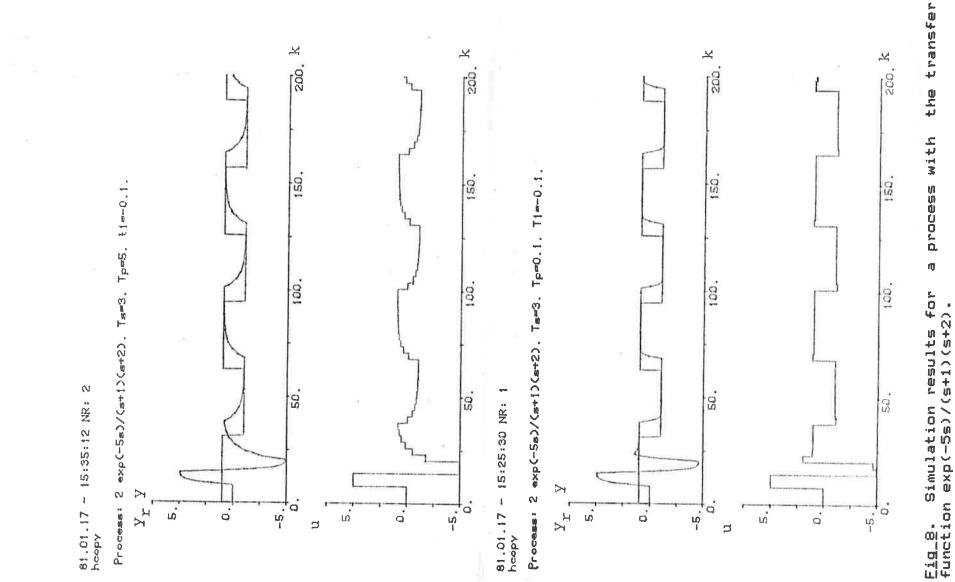
from



the Process with л**л** and imulation of algorithm 2
function exp(-0.5s)/(s+1) Simulation of <u>Fig.</u>7. 5 transfer

from automatically adjusted ښ. ۲ : sampling period then to 0.7 s. The A. The to 1.4, 5. 0

from automatically adjusted U H period sampling **.** The 0.7 , m **t** 0.35 en applied to processes stems with the transfer exp(-5s)/(s+1)(s+2)(s+3) ves some results. been app Systems gives having higher order dynamics. Sy functions exp(-5s)/(s+1)(s+2) and are simulated using SIMNON. Fig.8 g also has self-tuner simple The



7. REFERENCES

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> LUTFD2 CODEN: (1). 2.Astrom K.J (1979): Simple Self-tuners (TFRT-7184) / 1-063 / (1979).

STUPID CODEN: 3.Wittenmark B; Hagander P. and Gustavsson I. (1980): Implementation of a Self-tuning PID-controller. LUTFD2 / (TFRT-7201) / 1-030 / (1980).

Time Dead O. J. M. (1957): Control of Loops with L Engineering Progress. 53 217–219. 4.Smith O Chemical

Q Method for Automatica. 5.Young P. C. (1970): An Instrumental Variable Real-time Identification of a Noisy Process. Au 271-287.

÷ System Dead Time. Control and Parameter-adaptive ant or Timevarying Identification 6.Kurz H. (1979): Digital Para Processes with Unknown Constant Proc. 5th IFAC Symposium on Parameter Estimation. Darmstadf.

SIMNON PROGRAM ä APPENDIX

regulator . р . 4 parameters . NFU delay Parameters NF4 NP25 time the NF3 NP24 placement and ព្រួ extra rt) with Extra F4 P25 NF2 NP23 NYF1 two more F3 P24 UF1 process YF1 UF NF1 i NP22 i NP55 i NP55 NU4 Two More M N N H N on pole B with t NT5 NP15 NP45 F1 F22 F53 £NN order 47 (X+ak) with U3 NT4 NP14 NP44 T5 P15 P45 NU2 first based the polynomial Self-tuner PROC1 T4 P14 P44 NT3 NP13 NP35 NU1 else N ⊐ REG1 13 513 513 ي. ا SYSTEM Ф 5 NT2 NP12 NP34 × 40 ° SYSTEM NΥ1 then P12 P34 algorithm X+K*U)/to Ř ۲ï NP33 NYR1 "Self-tuner TS T1 P11 P11 P33 P33 P33 N71 N71 NP11 ΥR CONTINUOUS t <nk ×A $\supset \succ$ can hand DISCRETE "Process ≻ nk:1000 OUTPUT ak:0.5 DUTPUT TSAMP STATE STATE STATE STATE STATE NEW STATE DER INPUT INPUT 1 "The TIME y=if dx=(-TIME k = 1 NEN NEM NEW ţ, **UND**

.

Design Regulator N "Part

NUF

```
p1=-exp(-dt/tp)
ps=1+p1
a1=t1
b1=t2
b2=t3
b2=t4
bd=t5
bd=t5
bd=t5
bd=t5
bm1=max(abs(b1),abs(b2))
bm2=max(abs(b3),abs(b4))
bmax=max(bm1,bm2)
                                                                                                                                w1=a1-1
w3=tt1+p1-w1
w4=tt1*p1+a1
```

d12=b2-w1*b1 d22=b3+a1*b1 d23=b2+b4/a1 d33=b3+w1*b4/a1 h=-a1*(d22*(d33+a1*b1)-d23*(d12*a1+b4)+w1*(b1*b4-d33*d12))
"Test common factor
an=abs(n) tcom=0.001*bmax*bmax*bmax
bc2=b2-a1*b1 bc3=b3-a1*bc2 nc=b1+bc2+bc3
<pre>t0=if an(tcom then ps/(b1+bc2+bc3) else ps/bs dr11=w1-w4/w3 dr12=b2-b1*w4/w3 r11=-a1*w3*(b3*(d33+a1*b1)-d23*(dr12*a1+b4)+w1*(b1*b4-d33*dr12)) r12=(tt1+ps)*(bc3+bc2)-b1*tt1*p1 r12=(tt1+ps)*(bc3+bc2)-b1*tt1*p1 r1=if an)tcom then r11/n else r12/nc s01=-a1*w3*(dr11*(w1*d33+a1*d23)+a1*(a1*b1+d33))</pre>
succentrifier the solution of
"Control signal
uO1=(1-r1)*u1+(r1-r2)*u2+(r2-r3)*u3+r3*u4 uO=t0*yr+t0*tt1*yr1-s0*y-s1*y1+u01 u=if u0(ulow then ulow else if u0)uhigh then uhigh else u0
kO=if abs(sO+s1))0 then tO*(1+tt1)/(sO+s1) else 0
"Part 1 Estimation
yf=-tt1*yf1+y uf=-tt1*uf1+u e=yf-yf1-t1*f1-t2*f2-t3*f3-t4*f4-t5*f5
"Estimator Gain
k1=p11*f1+p12*f2+p13*f3+p14*f4+p15*f5 k2=p12*f1+p22*f2+p23*f3+p24*f4+p25*f5 k3=p13*f1+p23*f2+p33*f3+p34*f4+p35*f5 k4=p14*f1+p24*f2+p34*f3+p44*f4+p45*f5 k5=p15*f1+p25*f2+p35*f3+p45*f4+p55*f5
d=1+f1*k1+f2*k2+f3*k3+f4*k4+f5*k5
"update Estimate
nt1=t1+k1*e/d nt2=t2+k2*e/d nt3=t3+k3*e/d nt4=t4+k4*e/d nt5=t5+k5*e/d

"Update Covariance

nf1=yf1-yf nf2=uf-uf1 nf3=f2 nf4=f3 nf4=f3 nf1=y nu1=u nu2=u1 nu2=u1 nu2=u2 nu1=y nyf1=yf nuf1=yf "Update Sampling Time

ts=t+dt

dt:1.5 lam:0.98 t1:1.E-3 t2:1.E-3 t3:1.E-3 t5:1.E-3 t5:100 p33:100 p33:100 p33:100 p33:100 p33:100 p11:100 p33:100 p11:100 t1:100 t1:1000 t1:1000 t1:1000 t1:1000 t1:1000 t1:1000 t1:100

END

CONNECTING SYSTEM CONRI

TIME T yref=sign(sin(a0*t)) yr[reg1]=yref y[reg1]=y[proc1] u[proc1]=y1[delay] td1[delay]=t-td u1[delay]=u[reg1]

a0:0.05 td:5

END

. $\rightarrow 0$ LISTING PROGRAM 88 ф APPENDIX

PROGRAM SELFTUNER2(1);

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self-tuning PID-controller Automatic . with es if squares several least squares estimation 89 parameters (1980) Severa adaptive ÷ processes files schedurer. . (1979) implementation processes with recursive least estimation and in explicit ed on explicit bed in Astrom from estimated Self-tuners stored period for for simple given. microcomputer ğ Ы is described . ¥ Can (1981): Sampling based performs on-line uare root (SR) ښ. ۱ Astrom delay is calculated (CC) respective logging command Wittenmark B., Hagander results algorithm and (RLS) or square root regulator calculations noyz the with time delays. ou Z.Y. (1980) A datalogging and r pole-zero-placement Z Υ. 1980 ÷ and square AII Adjustment Zhou Nov. К.J. control ne program (RLS) or delay. References STUPID Mattsson report Astrom time noyz Author time Data The The

. automatically is adjusted period sampling the and

program main files: and communication calculation. these program. consists of foreground estimator. regulator operator program 1 - İ **DPCOM** The RLS Ü 2

r h

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8.02 **5**pole.tsamp.ta.ni.hhi.hlo.dampl.damph.lambda.po. lolim.hilim.aoa.boa.bob.boc:real; nd.ns.nta.ntb.np.yrchan.ychan.uchan.outchan:intege real; real; real; 8.8% real specif,comparsspecificationtype; 44 00 ť real; 40 iogth: array[1..n,1
logregpar:array[1..m,1
loguy: array[0..2,1 specificationtype=record array[1..n] ÷ h t0, r1, r2, s0, s1: real DECLARATIONS th.fitarray[1..n] estpar:estpartype; estpartype=record regpartype=record logpartype=record log:boolean; DATA end; end end 1 = 1 80endi ä #____ n=4 5 GLOBAL const type 502

```
regpar:regpartype;
logpar:logpartype;
i.j.k.s.w.period:integer;
yr.yroldyy.yold.u.u1.uold1.uold2.uold3.td.t:real;
yf.yfold.uf.ufold:real;
newpar:boolean;
                                                                                                         real
                                                                                                           ÷
                                                                                                        delu:array[1..100]
```

{ EXTERNAL PROCEDURE DECLARATION }

```
8.01
 adin(chan:integer):real;external;
rform(r:real; size:integer):integer;external;
daout(chan:integer; value:real);external;
schedule(procedure FG; var period:integer);external
clksave;external;
clkrestore;external;
Function
Function
Procedure
Procedure
Procedure
```

{ END OF GLOBAL }

Procedure estima Procedure regdes Procedure delayu	estimation(y:real; regdesign(specif:s delayu;external;	estimation(y:real; var estpar:estpartype); external; regdesign(specifispecificationtype;estpar:estpartype; var regpar:regpartype);external;
{=====================================	11	======================================
<pre>{ The procedure Adin input Control calcu Daout calcu Estimation es Regdesign ca Display displ Display displ delayu delay Updata prepa delayu delay</pre>	FG is lates (t) tates c tates c ts u(t) timates lculate reens reen	organized as follows: and y(t); ontrol signal u(t) from measurements parameters of given process; the parameters of the process; the reglator parameters ; meters of estimation and reglator a for store in files after running; utput of control signal; t and output for next step. }
<pre>{</pre>	ol; control sig reglator par ompensation y,rpoly:real	signals u(t) from measurements (yr parameters (t0, s0, s1, r1) and on ub. } eal;
with regpar, specif, estpar d tpoly:=t0*yr+t0*ta*yrold; spoly:=s0*y+s1*yold; rpoly:=(1-r1)*uold1+(r1-r u1:=tpoly-spoly+rpoly; u:=u1; if u1 (lolim then u:=lolim if u1 hilim then u:=hilim end end { { of control }	pecifiestpar do r+tO*ta*yrold; +s1*yold; 1)*uold1+(r1-r2 poly+rpoly; then u:=lolim; then u:=hilim; ol }	tpar do begin yrold; +(r1-r2)*uold2+r2*uold3; ly; =lolim; =hilim;
ure disp isplays n screer	lay; parameters of 1 }	· the process and the regulator
<pre>uth specifyestpa if s=ns then be writeln('poi for i:=1 to write(' write(' '); write(' '); write(' ');</pre>	stpar,regp h begin to int',k) c' c' c' c' c' c' c' c' c' c'	<pre>ar do begin ggin ggin write(th[i]:8:4) write(t0:8:4); write(t1:8:4); write(r1:8:4); write(r2:8:4); write(r2:8:4);</pre>
write(' write(' write('		write(s1:8:4); write(u1:8:4); write(u1:8:4);

|--|

```
and (k(=ntb) then logdata;
if (k)=nta) and (k(=ntb) t
updata;
k:=k+1;
if newpar then begin
specif:=compar;
period:=round(50*tsamp);
newpar:=false
                                                                                                               \mathbf{A}
                                                                                                               foreground
                                                                                                               40
                                                                                      end
end
end; { of
```

8.85 SELFTUNER2(1) PROGRAM

```
5...
                                  Automatic
                                                                                                     Û
                                                                                     Wittenmark B., Hagander P. and Gustavsson I. (1980):
STUPID Implementation of a self-tuning PID-controll
Mattsson S.E.(1978):A simple real-time schedurer.
report CODEN:LUTFD2/(TFRT-T156)/1-010/(1978).
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                                                                             squares estimation
                                                                                                                                                                    processes with
                                                                                                                                                sareups
                                                                                                                                                                                                                          parameters
                                                                                                                                                         several
                                                                                                                                                                                                     adaptive
                                                                  implementation of
                                                                                                                                                                              files
                                              p rocesses
                                                                                                                                                                                                               (1979)
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                                  with
                                                                                                                                              recursive least
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                                                                                                                                                                                                     explicit
                                                                                                                                                                                                                Astrom
                                                                                                                                                                                                             bed in Astrom
from estimated
                                                                                                                                                                               stored
                                  Self-tuners
                                             for
For
                                                                                                                                                         estimation
                                                                                                                                                                    simple
                                            period
                                                                                                                                                                                      given.
                                                                                                                                                                                                                                                           10.00
                                                                                                                                                                                                                                    adjusted
                                                                             datalogging and recursive least
                                                                                                                                                                                                                                                        program consists of these files
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D
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                                                                  A microcomputer
  5
                                                                                                                                                                                                               is described
                                                                                                                                                                   (RC) for
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                                                                                                                                                                                                                                                                                calculation.
                                                                                                                                                                                can
                                Zhou (1981):
the Sampling
                                                                                                                                                                                                     based
                                                                                                                                              performs on-line
                                                                                                                                                                                         (ل)
۱۰۰
  Astrom
                                                                                                                                                       root (SR)
                                                                                                                                                                                                                          delay is calculated
                                                                                                                                                                                                                                                                                            foreground program
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adin(chan:integer):real;external; rform(r:real; size:integer):integer;external; daout(chan:integer; value:real);external; schedule(procedure FG; var period:integer);external; clksave;external; clkrestore;external; Procedure Procedure Procedure Procedure Function Function

{ END OF GLOBAL }

edure Opcom; The provision	
rocedure alize itestpar itregpar ituy	PCUM I PCOGNI Nitial Nitial Nitial
	gıves specıtıcatıons; calculates desired polynomial. lists available commands. modefies parameters: reade the identifiere:
get take askboolean initestpar desiredool	s parameter if it s parameter if it s command if it i
Stop Stop Disp Store Store Store	gives a sensible orror message if in error. runs the selftuner. stops the selftuner. display the current parameters. logs inputs and output.
	logs estimated parameters. logs reglator parameters. stops the whole program and exits it into computer.}
<pre>{ DECLARATIONS OF OPCOM } label 999; const idlength=8; blank=' '; type identifiertype=array[1 opindex=(xhelp,xpar,xr xresultu, xex asindex=(spole,stsamp); suchan,soutch suchan,soutch errors=(fewarg,manyarg var identifier:identifiert operation: array[asind xop:opindex; sas:asindex; ch: char; logdata,logtheta,logre froceDURE FOR OPCOM } </pre>	<pre>IONS OF OPCOM > mgth=8; k=^'; r=''; tifiertype=arrayf1idlength] of char; dex=(xhelp.xpar.xrun.xstop.xdisp.xstore.xresultp, xresultu. xexit.xlastop); dex=(spole.stsamp:sdampl:sdamph:snp.sni.slambda, spo.sta.shhishlo.slolim.shlim.snd.sns.snta, spo.sta.shhishlo.slolim.shlim.snd.sns.snta, spo.sta.shhishlo.slolim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.shlim.snd.sns.snta, spo.sta.shnishlo.slolim.shlim.shlim.snd.sns.snta, suchan.soutchan.slastas); suchan.soutchan.slastas; suchan.slastas; suchan.soutchan.slastas; suchan.soutchan.sl</pre>
1549 1111 1011	e commands and information on screen } writeln; Simple Self-tuner');

7 t
writeln('The available commands are as follows:'); writeln:
); writeln(' ':12,'STORE');
<pre>':4,'RUN'); writeln(' ':13</pre>
<pre>' ':4,'STOP'); writeln(' ' o;</pre>
writeln('The parameters can be changed:'); writeln:
writein; writeln(* ':4,'POLE,TSAMP,TA,NI,HHI,HLO,LAMDA,PO, ND,NS,NTA,NTB,NP,DAMPL,DAMPH,LOLIM,HILIM.'};
writeln; writeln('The initial values can be assigned:');
writeln; writeln('The channels can be chosen:');
writein; writein('':4,'YRCHAN,YCHAN,UCHAN,OUTCHAN'); writein end; { of help }
Procedure error(errierrors); { gives a sensible error message }
, 1 1
warg: writeln('too few arguments')
many arguments / Lifier, ':illegal
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. † 1 le:
goto
Procedure initestpar; { initializes th, fi and o }
1 to r
for]:=1 to n do if i=1 then o[i,1]:=oo else o[i,1]:=0.0;
th[2]:=boaf th[1]:=bocf
endi 1 of Initestpar >
<pre>Procedure inituy; { initializes input and output }</pre>
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н н - Н
d:=0.0; d:=0.0; ufald:=0
=0.0; uald1:=0.0

uold2:=0.0; uold3:=0.0; daout(0,0.0); daout(1,0.0) end; { of inituy }	
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pole:=2; tsamp:=1.2; vi:=0 001: vo:=50:	
. 98;	
hhi:=0.78	
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marly ntarely	
ns:=50;	
aoa:=-0.01; boa:=0.01; hoh:=0.01: hon:=0.01:	
e; vrchan ²	
outchan:=1; hd:=3; end	
end; { of initspecif }	
[initregpar}
rocedure initregpar;	i
{ initializes reglator parameters }	
uegun with reapar do beain	
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ssignment[stsamp]:= '	
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assignment[sdamph]:= 'DAMPH '; 	
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ssignment[slambda];=	
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ssignment[sta]:= ?	
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ssignment[slolim]:= '	

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end; { of get }	
900%	d:boolean
t reads a command var comname:array[1	reads a command if it is a boolean } comname:array[1idlength] of char;
begin comname:=iden	tifiers
if ch=blank then get	ident
10	
ident	omname
end; t ot askboolean	ean y
frocedure cari	{
f updates param	parameters }
p:speci	.iontype;
begin if adly thay avver(fewers)	
pp:=compar;	
repeat getident;	10
assignment[s]	assignment[slastas]:=identifier;
sas:=spole; while assignm	pole; assignment[sas]{}identifier do sas:=succ(sas);
	take(pp.pole);
	take(pp.tsamp);
sdampl; ta sdamph; ta	take(pp.dampl); take(pordamph);
_	t(pp.np);
	take(pp.ni);
:epq	take(pp.lambda);
004 104 104 104 104 104 104 104 104 104	take(pp.po); take(pp.ta);
	take(pp.hhi); take(pp.hhi);
im:	im)
im:	take(pp.hilim);
570: 1711 20	get(pp.nd/) act(pp.sc);
	ttop.nta); dt(op.nta);
	t(pp.ntb);
	take(pp.aoa);
	take(pp.boa);
sooos ta shor: ta	take(pp.boo); take(pp.hoc);
an :	t(pp.yrchan);
	get (pp.ýchan) 🕴
	get (pp.uchan) ;
han:	
slog: as siactas: er	askboolean(pp.log); error(noname)
endi	
writeln(identifier,'has until eoln:	ifier, has been read')
newpar:=false;	
compar:=pp; with compar do	
itestpar	
end;	

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writeln(outfile)
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for i:=1 to n do write(outfile,logth[i,w]:8:4
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logdata:=false;
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logdata:=false;
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====CODE OF MAIN PROGRAM} 11 11

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begin
    period:=0;
    clksave;
    clksave;
    schedule(foreground,period);
    opcom;
    clkrestore
    end. { of main program }
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PROGRAM SELFTUNER2(1);

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                                 Automati
                                                                                    Wittenmark B., Hagander P. and Gustavsson I. (1980):
STUPID Implementation of a self-tuning PID-controll
Mattsson S.E.(1978):A simple real-time schedurer.
report CODEN:LUTFD2/(TFRT-T156)/1-010/(1978).
                                                                         estimation.
I. (1980):
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0, r1, r2, s0, s1: real

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specif.comparsspecificationtype

estpar:estpartype;

regpar:regpartype;

logpar:logpartype; i,j,k,s,w,period:integer;

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yr,yrold,y,yold,u,u1,uold1,uold2,uold3,td,t:real;
yf,yfold,uf,ufold:real;
newpar:boolean;
                                                         real ;
                                                        ÷
                                                      delu:array[1.,100]
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{ EXTERNAL PROCEDURE DECLARATION }

adin(chan:integer):real;external; rform(r:real; size:integer):integer;external; daout(chan:integer; value:real);external; schedule(procedure FG; var period:integer);external; clksave;external; clkrestore;external; Function Procedure Procedure Procedure Procedure Function

{ END OF GLOBAL }

rructure estimation(y'real, var estpartestpartype); { The procedure RLS calculates a Recursive Least Squares estimation for a first order process and the differences beteewn the filterred input and output signals are used.}
iy[1n] of real;
urgin with specif,estpar do begin vf:=-ta*vfold+v:
uf:=-ta*ufold+u; r:=1;
<u>م</u>
fil[]]=0; for]=1 to n do fil[]]=fil[i]+p[i,]]*fi[]];
end; for i:=1 to n do
t h f i ≟ = = 1
ir D
end;
{=====================================
<pre>/ The propedure PC deriver vegpartype); / The propedure PC deriver * vegualator * vegoutype);</pre>
explicit adaptive pole-zero-placement algorithm order oronese with a time delay
requalities imply two test values:
tcomfeatortoz for test of common factor, and tdampz=-b2/b1 for test of well damped zero. }
maxv,bminv,tsampd: eger;
adjust:boolean;
rocedure maxmin;
{ Detemnine the bmax and bmin from b1,b2 and b3. } begin
h specifiestpar do begin
al:=-th[]; bl:=th[2]; b2:=th[3]; b3:=th[4];
) abs(b2) then beg
bmin:=2;
bmax:=Z; bmax∨:=bZ; bmin:=1; bmin∨:=b1;
eno; if abs(b3)>abs(bmaxv) then begin bmax:=3; bmaxv:=b3;

```
r2:=(b2*b2*(w1+as1*r1)+b1*b2*a1*r1)/nsum$
s0:=(b2*((as1+a1*a1)*r1+as1*w1)+b1*(a1*as1*r1+a1*w1))/ns
                                                                                   calculator}
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    r1:=((as1+ta+p1)*b2*b2+(a1-ta*p1)*b1*b2)/nsum5
                                                                                                                                                                                                                                                                                                                                                 begin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              begin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         s1:==(b2*(-a1*as1*r1-a1*w1)-a1*a1*b1*r1)/nsum
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                                                                                                                               process.
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                                                                                                                                                                                                                                                                                                                                                                                           s0:=(r1+a1*r1-a1+ta*p1)/b1
s1:=-a1*r1/b1
  11.011
 then bmin:=3
                                                                                                          parameters
                                                                                                                                                                                                                                                                                                                                               and
                                                                                                                                                                                                                                                                                                                                                                     r1:=ps+a1+ta+b2/b1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             and
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           s0:=(as1+ta+p1)/b1
s1:=(ta*p1-a1)/b1;
                                                                                                                              the time delay of the controlled
var p1,ps,as1,bs,w1,nsum:real;
                        b2:=th[4];
                                                                                                                     the
                                                                                                                                                                                                                                                                                                                                              (-b2)dampl*b1)
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                                                                                                                                                                                                                                                                                                                                                                                r2:=r1*b2/b1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                       rl:=asl+pl+ta;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            11
                                                                                                                                                                              bs:=b1+b2
                                                                                                                                                                                                                                                                                                            s0:=(r1+ta*p1)/b1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           s0:=(ps+ta-r1)/b1
                                                                                                                  respectively, where Ts is
                                                                                                                                                                                                                            -
                                                                                                                                                                                                                                                                                                                                                           t0:=ps/b1;
                                                                                                         the regulator
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         to:=ps/b1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   r1:=b2/b1;
                                                                                                                                                                                                              w1:=p1*ta-a1;
nsum:=(b1+b2)*(a1*b1+b2)
                                                                                                                                                                                                                                                                                                                                                                                                                                            to:=ps/ps;
abs(b3){abs(bminv)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                r2:=0.05
          bmin=1 then begin
                                                                                                                                                                                        p1:=-exp(-pole*tsamp);
                                                                                                                                                                                                                                                                                                                                                                                                                                 begin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               begin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    ta*p1;
                                                                                                                                                                                                                                      do begin
                                                                                                                                                                                                                                                                          t0:=ps/b1;
                                                                                                                                                                                                                                                                                    r1:=ps+ta;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       to:=ps/b1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                then
                                                                                                                                                                 do begin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      0
                                                                                             calculator;
                                                                                                                                                                                                                                                                                                r2:=0.0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               r2:=0.05
                                                                                                                                                                                                                                                                                                                        51 = 0.0
                                                                                                                                                                                                                                                 then
                                                                                                                                                                                                                                                                                                                                                                                                                                 else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    end
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      0
H
                                                                                                                                                                                                                                                                                                                                                                                                                      end
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   end
                       b1:=th[3];
                                                                                                                                                                                                                                                                                                                                              ц.
н
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 bmin()1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             ц.
Н
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   r1 :≡
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      regpar
bmin=1
                                                                                                                                                                                                                                                                                                                                               else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              else
                                                                                                        Calculates
                                                                                                                                                                                                                                                                                                                                   end
                                                                                                                                                                            -
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   end
                                                                                                                                                                 with specif
as1:=1+a1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             ц.
.н
                                                                                                                                                                                                                                                              4
                                                                                                                                                                                                    ps:=1+p1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                ц.
191
                                   end
                                                                                             Procedure
ц.
н
                                                                                                                                                                                                                                       with
                                                                                                                                                                                                                                                 4
                                               endi
                                                                                                                                                      beg i n
                                                         end;
                                                                                                        ų
                                                                                 ŵ
```

r2:=0.0; 50:=((as1+ta+p1)-r1)/b1; 51:=-a1*r1/b2; end:
end; end; end;
<pre>{</pre>
begin with specif do begin tdi:=(a1*b1+b2)/(a1*(b1+b2)); if (tdi)0) and (a1)0) then begin
to;=-tsamp*In(tol)/In(al); if bmin=1 then td:=td+tsamp; t:=-tsamp/In(al); end;
if k>np then begin if tsamp>(hhi*td) then tsampd:=tsamp-ni; if tsamp<(hlo*td) then tsampd:=tsamp+ni; if tramp>(hlo*td) then tsampd:=tsamp+ni;
{modifyestpar} Procedure modifyestpar; var afa,bata,tmd:real; tdt,tt:integer;
begin with specif,estpar do begin afa:=ln(al)/tsamp;
bata:=(b1+b2)*ln(a1)/(tsamp*(1-a1)); th[1]:=-exp(-afa*tsampd); tdt:=trunc(1000*td); ++*-+*********************************
twd:=0.01*(tdt mod tt); b1:=bata*(1-exp(-afa*(tsampd-tmd)))/afa; c0:=_c1:=*ts1*c^c=c=*ts1*c^c=*.c2**.c2**.c2**.c2**.c2**.c2**.c2**.c
uz:=-uata*tntl]*(exp(ata*tmu)-l)/ata; if bmin=1 then begin th[2]:=0.01; th[3]:=b1;
else begin th[2]:=b1; th[3]:=b2;
9 L
end;

```
tsamp:=tsampd;
                              with specif do begin
maxmin;
calculator;
calculator;
modifytsamp;
if adjust then begin
modifyestpar;
newpar:=false;
with compar do tsam
newpar:=true;
end;
end;
             Ψ
          { code of regdesign
                     begin
```

٩ł PROGRAM LISTING ü APPENDIX

PROGRAM SELFTUNER2(2);

PID-controller. Automatic with es if Š sareups e-t are used to sense severa adaptive estimatoi Processes implementation of (1980): files in Astrom (1980). real-time schedurer. processes CODEN:LUTFD2/(TFRT-T156)/1-010/(1978) with recursive least it and explicit : least sqares e Gustavsson I. a self-tuning P stored Self-tuners for estimation simple Period given. c 0 þ .Y.(1980):A microcomputer К. Ј pole-zero-placement is described for n) can Sampling :(6791) simple based recursive and Astrom performs on-line . 1 4 (SR) (CC) command datalogging and recurs Wittenmark B., Hagander STUPID Implementation Mattsson S.E.(1978):A si results root algorithm and regulator calculations Zhou the estimates delay. Z.Υ. 1980. logging and square ť All Adjustment Zhou with Time Dec. К.Ј. control delay. program respective group of report References 5 O Astrom N Authors Zhou (RLS) time Data The The đ 4

sampling the and process s with two priods controlled proces automatically đ adjusted time delay of يں ۱۰۰ period the

~ . program and main 84 files operator communication calculation consists of these program. foreground estimator. regulator program İ I OPCOM The RLS ĉ Ű

ሐ DECLARATIONS GLOBAL DATA 4

nd.ns.nta.ntb.np.yrchan.ychan.uchan.outchan:integer; pole.tsamp.ta.ni.hhi.hlo.dampl.damph.lambda.po lolim.hilim.aoa.boa.bob.boc:real; -₫Ţ Net Net Net real real real rea! ښ م real; 4 4 4 44 Ö ..n.1..n] logth: array[1...,1]
logregpar:array[1...,1]
loguy: array[0...2,1..1] ч О ..n] specificationtype=record 10 t0, r1, r2, s0, s1: real th.fi.array[1..2.1
p: array[1..2.1 estpartype≂record logpartype=record regpartype=record log:boolean; endi endi endi end 1=180; n=45 $\nabla = M$ const type

ſ <u>ں</u> estpar:estpartype; regpar:regpartype; logpar:logpartype; q.i.j.k.s.w.period:integer; yr.yrold1.y.yold1.u.u1.uold1.uold2.uold3.real; yf.uf.yfold.ufold:array[1..2] of real; bmin:array[1..2] of integer; newpar.insample.desample:boolean; delu:array[1..100] of real; ss:array[1..100] of integer; 8.05

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{ EXTERNAL PROCEDURE DECLARATION >

adin(chan:integer):real;external; rform(r:real; size:integer):integer;external; daout(chan:integer; value:real);external; schedule(procedure FG; var period:integer);external; clkrestore;external; clksave;external; Procedure Procedure Procedure Function Function Procedure

{ END OF GLOBAL }

stpar:estpartype); cationtype;estpar:e
var regpariregpartyp nalj
{ The procedure FG is organized as follows: Adin inputs yr(t) and y(t);
regl
the parameters of th
kegdesign calculates the reglator parameters ; Display display parameters of estimation and reglator on screen;
delays the output of cont
ta updates input and
{control; Procedure control;
ulates control signals u(t) from mea
and y // regratur parameters / to/ su/ si/ ri integral compensation ub. }
er 14
rpoly:=(1-r1)*uold1+(r1-r2)*uold2+r2*uold3; u1:=tpoly-spoly+rpoly;
u:=ul; if ut (lolim then u:=lolim;
. 4 .
ena else u:=uold1;
end; { of control }
{display} Procedure display\$
f displ
with specif;estpar;regpar do begin if s=ns then begin
rite or c
U r
umiriqi-i ther if q-1 then write(' h(Td, h=',tsamp:8:4)
write(` min[q]=3 t
write(' h)Td' h=',tsamp:8:4)

else write(* 2h)Td, writeln; end;	Tc=',2*tsamp:8:4);
te(' '); write(t0:8	
	- 44B
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	·
2 2 2 2 MULTERULES 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	
WFICELT!	
end ; e :::::::::::::::::::::::::::::::::::	
end; { of display }	
Procedure loodata;	
ares data and parameters from	k=nta to k=ntb for
tore in files aft	
ogpar,estpar,regpar do begin 	r.
o logthliw/:=thly	
1874	
e- 1	
ogregpartviw:=Frv;	
logregparto,wi:=si, logregparto,wi:=ul logregerf7.w]:=u: w:=w±1	
end; { of loopar }	
	updata}
rocedure upd	
tes input and output preparing	for next step }
n.um:real;	
begin	
with estpar,specif do begin	
fi[1,4]:=fi[1,3];	
fi[1,3]:=fi[1,2];	
fi[1,1]:=vfald[1]-vf[1];	
fif1~1~1~1~1~1~1~1~1~1~1~1~1~1~1~1~1~1~1	
if odd(k) then houin	
fi[2,3]:=fi[2,2];	
fi[2,1]:=vfold[2]-vf[2];	
fi[2,2]:=uf[2]-ufold[2];	
vfold[2]:=vf[2];	
ufold[2]:=uf[2];	
yrold1:=yr;	
yold1:=y;	
1d2	
N -	
insample then	
ド 1 = 1 - 1 - 1	5.2 3 1 3
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thr2,2] thr2,2] thr2,3] thr2,3] thr2,3] thr2,3] thr2,3] thr2,3] thr1,2] thr1,3] thr1,3] thr1,3] thr1,3] thr1,3] thr1,3]	FOREGROUND }	<pre>th specif do begin yr:=adin(yrchan); y:= adin(ychan); control; daout(outchan.u); delayu; q:=1; g:=1; if odd(k) then begin q:=2; control*contron);</pre>	<pre>regdesign(specifyestparyregpar); d; splay; log then if (k)=nta) and (k(=ntb) then logdata; data; =k+1; newpar then begin specifi=compar; period:=round(50*tsamp); newpar:=false d of foreground }</pre>
	ena, tot up { t CODE FOREGR begin	<pre>with speci Yr= adin Yc= adin control; deoutrol; delayu couto couto delayu if odd if odd ckima if odd ckima if odd ckima if odd ckima if odd ckima if odd ckima if in the speci chima if in the speci couto co</pre>	end: regde display: if log t if log t k:=k+l; k:=k+l; if newpa specia end: f of for

PROGRAM SELFTUNER2(2);

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Gustavsson I. (1980):
a self-tuning PID-controller
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                                     Automati
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                                               Processes
                                                                       implementation of
                                                                                                                    S.E.(1978):A simple real-time schedurer
CODEN:LUTFD2/(TFRT-T156)/1-010/(1978).
                                     with
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                                  Self-tuners
Period for P
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                                                                      Z.Y.(1980):A microcomputer
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                                   (1979):
                                                                                            Wittenmark B., Hagander and
STUPID Implementation of a
Mattsson S.E.(1978):A simple
                                                                                                                                                        on-line
                                                                                  recursive
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                                   and Zhou
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Z.Y.
1980
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noyZ
          Dec.
                                   К.J.
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                                    Astrom
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sampling ų. H processes with to sense adaptive files . (1980) the in are used explicit in Astrom stored and process simple given. s with two priods controlled proces e Q c 0 automatically. described for results can command is based (CRC) results algorithm ŝ regulator calculations estimates pole-zero-placement n) respective logging adjusted delay of A11 control time delay. group of . . . time period The the ¢

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                                   main program
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 files
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                  calculation
 these
                          foreground program
 consists of
       estimator.
                 regulator
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The
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{ GLOBAL DATA DECLARATIONS }

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5.,
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                                                                                nd,ns,nta,ntb,np,yrchan,ychan,uchan,outchan:integ
                                                           pole,tsamp,ta,ni,hhi,hlo,dampl,damph,lambda,po,
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                                                                                                                                 real
                                                                                                                                                                                                                                                                           specif.compar:specificationtype;
estpar:estpartype;
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                                                                                                                                           ..n,1..n3
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                                                                                                                               th.fi.array[1..2.1..n]
p: array[1..2.1..n;
                                                                                                                                                                                                                 logth: arrayE1..n,1
logregpar:arrayE1..m,1
loguy: arrayE0..2,1
                                              specificationtype=record
                                                                                                                                                                               10.025
                                                                                                                                                                               t0, r1, r2, s0, s1: real
                                                                                                                                                                                                                                                                                                    regpar:regpartype;
                                                                                                                                                                                                                                                                                                              logpar:logpartype;
                                                                                                                                                                    regpartype=record
                                                                                                                     estpartype≂record
                                                                                                                                                                                                       logpartype=record
                                                                                            log:boolean;
                                                                                                                                                         endi
                                                                                                                                                                                                                                                     end;
                                                                                                         end
                       1 = 1805
                                                                                                                                                                                            end
n=45
          10
          m=7
const
                                              type
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8.8%

10 q,i,j,k,s,w,period:integer; yr,yrold1,y,yold1,u,u1,uold1,uold2,uold3:real yf.uf,yfold.ufold:array[1.2] of real; bmin:array[1.2] of integer; newpar,insample,desample:boolean; delu:array[1.100] of real; ss:array[1.100] of integer;

{ EXTERNAL PROCEDURE DECLARATION }

Bdh adin(chan:integer):real;external; rform(r:real; size:integer):integer;external; daout(chan:integer; value:real);external; schedule(procedure FG; var period:integer);external clksave;external; clkrestore;external; Procedure Procedure Procedure Procedure Function Function

{ END OF GLOBAL }

Procedure Opcom	
procedure	: organized as follows:
lialize initestoar	gnizes identifiers and init ializes estimated narameter
itregpar	.zes reglator parameters;
ituy itir	initializes input and output;
ıtspecıt siredool	gives specifications; calculates desived polvnomial.
	available commands
at i den	modefies parameters: reade the identifiere:
	parameter if it is
Û.	ads parameter if it is a
askooolean initestpar	លា ហ
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r ro r	ທ ໜີ. ທີ
	runs the selftuner. ctone the cel <i>t</i> tuner
ŤI	inputs and outp
Reculto	loon anti-atad nanamatann
£	
μ	logs reglator parameters.
error Exit	stons the whole program and evits it into computer >
TTONS OF O	
label 999; const idlength=8; black-2 25	
olanke' '; tvna idantifiantvo	000000151 44]052457 75 75055
opindex=(opindex=(xhelp;xpar;aytiiutenytn; or tnar; opindex=(xhelp;xpar;xrun;xstop;xdisp;xstore;xresultp; xresultu; xexit;xlastop);
asindex=(spol	spole·stsamp·sdampl·sdamph·snp·sni·slambda·
shtb	spoistaismuuismuuismuuumismuuumismuaismaa shtbisaoaisboaisbobisbocislogisyrchanisychani
	ا لي
errors=(tewar var identifier:id	rs=(tewarg,manyarg,noname,prierr,illfile,nolog); tifier:identifiertvoe:
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assignment:ar vootooindovi	գ. 0
sas as index	
ch: char; 10040405100446	
rogoara , rogra	a, loguneta, logvey, poplean,
<pre>{ PROCEDURE FOR OPCOM</pre>	2M >
rrocedure neip; { lists available hodin	e commands and information on screen }
for i:=1 to 5 do writeln(?	writeln; Simole Self-tuner');
writeinf	A JALLANS

error} -inituy} initestpar} 8.05 \sim :12, STORE');
'13, RESULTP');
'13, RESULTU');
'13, RESULTU');
'12, EXIT'); be reguired' p[q,i,J]:=0.0 writeln argument') follows:') \riteln(' ':4,'POLE,TSAMP,TA,NI,HHI,HLO,LAMDA,PO ND,NS,NTA,NTB,NP,DAMPL,DAMPH,LOLIM,HILIM.'); 8.01 value'); \sim assigned:' writeln(' ':4,'YRCHAN,YCHAN,UCHAN,OUTCHAN'); changed:'); fewarg: writeln('too few arguments'); manyarg:writeln('too many arguments'); prierr: writeln(identifier,':illegal va noname: writeln(identifier,':illegal ar nolog: writeln(identifier,':log do not file') else -P 84 writeln('The channels can be chosen:'); Ŵ writeln(' writeln(' ij, fiEq, i] =0.05 writeln(' writeln(' od I writeln; writeln('The initial values can be writeln; nolog: writeln(identifier,':log
illfile:writeln(identifier,':ill ':4,'AOA,BOA,BOB,BOC.'); ተ ŝ message \sim commands then p[q,i,J]: th[2,2]:=boa; 10 desample:=fal can be th[2,4]:=boc and output è, with comparyestpar do begin begin ۵. error(err:errors); : a sensible error and 'The parameters available n do th[q,i]:=0.01; 9 ÷ 0 ыp-10.00 ~ initializes input \sim 9 7:44,7 PAR') 7:44, RUN') ':4,'STOP' 00 initestpar ':4, DISP' initestpar; £ £ 5 th; if i=J N t t t0 19 i:=1 to Υ th£2,1]:=aoa; th[2,3]:=bob; ī Υ estpar do inituy; initializes for q:=1 to error The ۵. i = 1÷, hel ÷ for q:=1 writeln(' writeln(' for teln(' write(' '
write(' '
writeln; writeln(' writeln; case err 666 writeln(writeln; writeln; writeln; 50 for ÷ 4 ť gives write(⁷ write(' Procedure Procedure Procedure insam K:=1; W:=1; ų, oto with ų endi ų end; ÷ begin begin begin endi endi end ų ų ŵ D ų ŵ Ψ

<pre>end; for i:=1 to 20 do delu[i]:=0.0; yrold1:=0.0; yold1:=0.0; for q:=1 to 2 do begin yfold[q]:=0.0; ufold[q]:=0.0; end; uold1:=0.0; uold2:=0.0; uold1:=0.0; uold2:=0.0; for i:=1 to 100 do ss[i]:=0; daout(0,0.0); daout(1,0.0) end; { of inituy }</pre>	<pre>f</pre>	<pre>{ initializes reglator parameters } f initializes reglator parameters } begin with regpar do begin to:=1.0; r1:=0.0; r1:=0.0; s1:=0.0; end end; </pre>	<pre>{initialize; Procedure initialize; { recognizes identifiers and initializes } begin operation[xhelp]:= 'HELP '; operation[xdisp]:= 'BISP '; operation[xun]:= 'PAR '; operation[xun]:= 'PAR '; operation[xun]:= 'RUN '; operation[xstop]:= 'STOP '; operation[xstore]:= 'STOR '; operation[xstore]:= 'STOR '; operation[xstore]:= 'STOR '; operation[xstore]:= 'STOR '; operation[xstore]:= 'STOR '; operation[xstore]:= 'STOR '; operation[xstore]:= 'STOR '; operation[xstore]:= 'STOR '; operation[xstore]:= 'STORE '; operation[xstore]:= 'STOR '; operation[xstore]:= 'STOR '; assignment[stemp]:= 'DAMPL '; assignment[sdamp]]:= 'DAMPL ';</pre>

<pre>assignment(snpl:= 'NP '; assignment(snul:= 'NT '; assignment(spli:= 'NT '; assignment(spli:= 'NT '; assignment(spli:= 'TA '; assignment(spli:= 'TA '; assignment(spli:= 'TA '; assignment(spli:= 'HLI'N '; assignment(snul:= 'HLI'N '; assignment(snul:= 'ND '; assignment(snul:= 'ND '; assignment(snul:= 'ND '; assignment(snul:= 'ND '; assignment(snul:= 'NC '; assignment(spli:= 'NC '; assignment(spli:= 'NC '; assignment(sprchan1:= 'NCHAN '; assignment(sprchan1:= 'NCHAN '; assignment(sprchan1:= 'UCHAN '; ass</pre>
rocedure skipblank; begin repeat read(ch) until (ch{}blank) or eoln end; { of skipblank }
<pre>{getident; Procedure getident; { reads a identifier from the terminal } begin for i:=1 to idlength do identifier[i]:=blank; skipblank;</pre>
ů ř
<pre>{take} Procedure take(var rn:real); { reads a number if it is a real } begin if ch=blank then read(rn); if (rn(-1000) or (rn)1000) then error(prierr) else read(ch); if ch(> 1000) or (rn)1000) then error(prierr) else read(ch); end; { of take }</pre>

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get }
                                                                                                                                                                                                                      (ved
                                                                                             askboolean}
                                                                                                                                                                                                                                                                                                                           ; (sas:=succ(sas);
                                                                                                                                                                   then command:=true
                                                   8.05
                                                   read(ch)
                                                                                                     askboolean(var command:boolean);
; a command if it is a boolean }
                                                                                                                                                                                                                                                                                                                           8
                    Ψ
                                                                                                               boolean
                                                                                                                         char;
                                                                                                                                                                                                                                                                                                                          assignment[sas] <> identifier
                    integer
                                                                                                                                                                                                                                                                                                      assignment[slastas]:=identifier;
                                                   else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            askboolean(pp.log);
                                                                                                                         40
                                                                                                                                                                                                                                                                                                                                                                          take(pp.damph);
get(pp.np);
take(pp.ni);
take(pp.lambda);
take(pp.ta);
take(pp.ta);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   soutchan:get(pp.outchan);
                                                                                                                comname:array[1..idlength]
.n
        get(var inn:integer);
a number if it is a
                                                                                                                                                       getident;
                                                                                                                                                                                                                                                                                                                                                         10-10
                                                                                                                                                                                                                                                                                                                                                                                                                                                               805 - 805
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    get(pp.ychan);
get(pp.ychan);
                                       ch=blank then read(inn);
inn(0 then error(prierr)
ch()',' then read(ch)
                                                                                                                                                                                                                                                                                                                                                       take(pp.tsamp)
take(pp.damp1)
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                                                                                                                                                  period:=0;
clksave;
schedule(foreground,period);
                                                                                              { CODE MAIN PROGRAM }
Procedure foreground;external;
                                                                                               Ï
                                                                                           *********************************
                                                                                                                                                                                                             n,
                                                                                                                                                                                   opcom;
clkrestore
1. { of main program
                       xlastop:
                                           999: readln
until xop=xexit
end; { of opcom }
                                 endi
                                                                                                                                        beg i n
                                                                                                                                                                                                             end.
```

R.P. PROGRAM SELFTUNER2(2)

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U
                                                                                                Wittenwark B., Hagander and Gustavsson I. (1980):
STUPID Implementation of a self-tuning PID-controller
Mattsson S.E.(1978):A simple real-time schedurer.
report CODEN:LUTFD2/(TFRT-T156)/1-010/(1978).
                                      Automati
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                                    Self-tuners
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                                                                         .Y.(1980):A microcomputer
                                 (1979):
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                                    and Zhou
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Z.Y.
1980.
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                                                 Adjustment
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                                    К.Л.
                        References
                                    Astrom
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Author
            Data
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sampling processes with ц. .н sau enbs sense several adaptive files e. (1980). ed to se recursive least the and in L are used explicit Astrom stored bre estimation process simple given. in estimates with two priods å c 0 described automatically for nen Dan based controlled performs on-line ين. اب root (SR) (CC) command results algorithm regulator calculations time delay. All resul ۍ. ۱ Ŵ pole-zero-placement logging adjusted ц. O areups delay control program delay. respective ť 50 period is time dnou b (RLS) the The The ¢

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rh,
                                     main program
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consists of these fil
                                    communication
                  calculation.
                           foreground program.
       estimator.
                  regulator
                                    operator
program
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                                    OPCOM
The
       RLS
               RC
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Τ DECLARATIONS GLOBAL DATA ų

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p: array[1..2,1..n] uf r
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array[1..m,1.
array[0..2,1.
                                            specificationtype=record
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                                                                                                                                                                   -
                                                                                                                                                                 0, r1, r2, 50, 51 ; rea
                                                                                                                                                                                                    array[1
                                                                                                                                                                                                               logregpar:array[1
                                                                                                                                                                                                                                                                     estpar:estpartype;
                                                                                                                                                                                                                                                                                regpar:regpartype;
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                                                                                       log:boolean;
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                     1=1805
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n=4 5
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const
                                            type
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v
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110 q:i.j.k.s.w.period:integer; yr.yrold1,y.yold1,u.u1,uold1,uold2,uold3:real yf.uf.yfold.ufold:array[1..2] of real; bmin:array[1..2] of integer; newpar.insample.desample:boolean; delu:array[1..100] of real; ss:array[1..100] of integer;

{ EXTERNAL PROCEDURE DECLARATION }

8.01 adin(chan:integer):real;external; rform(r:real; size:integer):integer;external; daout(chan:integer; value:real);external; schedule(procedure FG; var period:integer);external; clksave;external; clkrestore;external; Procedure Procedure Procedure Procedure Function Function

{ END OF GLOBAL }

Procedure estimation(y:real; var estpar:estpartype); { The procedure RLS calculates a Recursive Least Squares estimation for a first order process and the differences beteewn the filterred input and output signals are used;} var r;e:real; fil:array[1n] of real; begin with specif;estpar do begin
beteewn the filterred input and output signals are used. r,e:real; fil:array[1n] of real; in ith specif,estpar do begin
h specifiestpar do
specitiestpar do
yt tq」:=~ta*ytoId tq1+y;
if q=1 then e:=yf[1]-yfold[1] else e:=yf[2]-yfold[2];
for is=1 to n do begin filfi3:=0:
for]:=1 to n do fil[i]:=fil[i]+p[q,i,]]*fi[q,]];
rserticq,11*t11(1,1) es=erfiCq,1]*thCq,1]
end; fos i:=1 +0 > do
th6q,i]:={
for i:=1 to n do for to n do horis
CQ C C C C C C C C C C C C C
lt 1=J Them ptq,1,JJ:=ptq,1,JJ/lamoda; endi
end 5
end
rruceuure reguesignispecir.speciricacioncype, estpar.estpartype; Var regpartype);
edure RC designs a regulator according to Astr
explicit adaptive pole-zero-placement algorithm for a first order process with a time delav.
ies imply two test values:
test of common facto
rur test ur weil uampeu zeru. Naxv,bminv,tsampd:real;
{
Procedure maxmin; / Datawaina tha haay and hain faan hijho and ho b
ריה מוויפא פרים מוודנו דליטון פריים פרים סלי
specifyestpar
tor q:=1 to z do begin al:=-th[o,1];
abs(b2) {
omaxi=1; omaxvi=01; bminfq];=2; bminv;=b2;
J 1
bmin∨:=b1
if abs(b3))abs(bmaxv) then begin
bmax:=3; bmaxv:=b3;

```
SO:=(b2*((as1+a1*a1)*r1+a1*b2*a1*r1)/hsum;
S1:=(b2*(-a1*a1*a1)*r1+as1*w1)+b1*(a1*as1*r1+a1*w1))/hs
s1:=(b2*(-a1*as1*r1-a1*w1)-a1*a1*b1*r1)/hsum
end;
                                                                                                              calculator}
                                                                                                                                                                                                                                                                                                                                                                                 begin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    then begin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        r1:=as1+p1+ta;
r2:=(b2*b2*(w1+as1*r1)+b1*b2*a1*r1)/nsum;
                                                                                                                                    Ts>Td
                                                                                                                                                                                                                                                                                                                                                                                then
                                                                                                                                                 <u>ل</u>.
                                                                                                                                                                                                                                                                                             then begin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 then begin
                                                                                                                                               PL
                                                                                                                                    and
                                                                                                                                                                                                                                                                                                                                                                              (-b2 (damph*b1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   (-b2(damph*b1)
                                                                                                                                                and
                                                                                                                                    Ts (Td
                                                                                                                                              : is the sample period controlled process. }
              then bmin[q]:=3;
                                                                                                                                                                                                                                                                                                                                                                                                                              abs(nsum)(abs(0.01*bmaxv*bmaxv)
                                                                                                                                                                                                                                                                                            abs(nsum)(abs(0.01*bmaxv*bmaxv)
                                                                                                                                                           process.
                                                                                                                                                                                                                                                                                                                                                                                                                            50:=(r1+a1*r1-a1+ta*p1)/b1
51:=-a1*r1/b1
                                                                                                                                  40
                                    b2:=th[q,4];
                                                                                                                                    parameters
                                                                                                                                                                                                                                                                                                                                                                                and
                                                                                                                                                                                                                                                                                                                                                                                                        R (P
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   .
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    and
                                                                                                                                                                                                                                                                                                                                                                                                     r1:=ps+a1+ta+b2/b1
r2:=r1*b2/b1;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 s0:=(as1+ta+p1)/b1
s1:=(ta*p1-a1)/b1;
                                                                                                                                                                                                                                                                                                                                                                               (-b2)damp1*b1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  (-b2)damp1*b1)
                                                                                                                                                                                                                                                                                                                                           8.0%
                                                                                                                                                                  pl,ps,asl,bs,wl,nsum!real;
                                                                                                                                                                                                          bs:=b1+b25
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                10
                       begin
                                                                                                                                                                                                                                                                                                                                          s0:=(r1+ta*p1)/b1
s1:=0.0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             s0:=(ps+ta-r1)/b1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             t0:=ps/b1;
r1:=b2/b1;
           abs(b3)(abs(bminv)
bmin[q]=1 then beg
                                                                                                                                                                                                                                                        .....
                                                                                                                                                                                                                                                                                                                                                                                          to:=ps/b1;
                                                                                                                                    the regulator
                                                                                                                                                                                                                                                        nsum:=(b1+b2)*(a1*b1+b2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                              t0:=ps/ps;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     r2:=0.05
                                                                                                                                             respectively, where Ts
                                                                                                                                                                                                                  p1:=-exp(-pole*tsamp);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     then
                                                                                                                                                                                                                                                                                                                                                                                                                                                                  begin
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      begin
                                                                                                                                                         the time delay of the
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       r1:=-ta*p1;
                                                                                                                                                                                                                                                                      begin
                                                                                                                                                                                                                                                                                                        t0:=ps/b1;
                                                                                                                                                                                                                                                                                                                   r1:=ps+ta;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           to:=ps/b1;
                                                                                                                                                                                                                                                                               then
                                   b1:=thEq,33;
                                                                                                                                                                                             do begin
                                                                                                                       calculator;
                                                                                                                                                                                                                                                                                                                              r2:=0.05
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  r2:=0.0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          s1:=0.0;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    bminE23 (>1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                  else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     else
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a
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                                                                                                                                                                                                                                                                    regpar do
bmin[2]=1
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.н
                                                                                                                                                                                                                                             w1:=p1*ta-a1;
                                                                                                                                                                                                                                                                                                                                                                                else
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     else
                                                                                                                                  Calculates
                                                                                                                                                                                                                                                                                                                                                                   end
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        end
                                                                                                                                                                                                        as1:=1+a1;
                                                                                                                                                                                                                                                                                            ц.
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.н
                                                                                                                                                                                             specif
                                                                                                                                                                                                                                 ps:=1+p1;
                                               end;
end;
if a
                       4
                                                           end;
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with ≤
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<pre>t0:=ps/bs; r1:=((as1+ta+p1)*b2*b2+(a1-ta*p1)*b1*b2)/nsum; r2:=0.0; s0:=((as1+ta+p1)-r1)/b1; end; end; end; end; for end; for /pre>
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<pre>{</pre>