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Abstract

This report present an implementation of an adaptive control algorithm, which allows to compensate the friction of a DC motor. An IBM Personal Computer with the DOS operating system was used. Two issues had to be added to use this computer for a real-time application: a scheduler and driver routines for the analog and digital 1/0 board. A Pascal program was written to perform experiments with this adaptive algorithm and to compare it with conventional regulators. Some measurements show the advantages of the adaptive algorithm compared with a controller without compensation and a controller with fixed compensation.

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I CONTENTS

II SYMBOLS

a	Parameter
$\tilde{a}$	Estimated parameter
b	Parameter
$\tilde{b}$	Estimated parameter
c	Constant
e	Estimation error
r	Reference signal
t	Time
T	Torque
u	Control signal
y	Output signal
α	Parameter
δ	Estimated parameter
τ	Time constant
ω	Angular velocity

1 INTRODUCTION

Whenever possible one tries to design a linear controller because the theory is well-known and easy to use. Nonlinearities in the plant are often responsible for poor performance of linear controllers.
If the nonlinearities of some processes are known, they can be compensated. For time-constant plants a fixed compensation will yield fairly good results, but if the plant is time-varying or the nonlinearities are not exactly known the compensation should be adaptive.
An adaptive compensation, as considered in this report, consists of two parts:

- estimation of the parameters of the nonlinear characteristic

- compensation with help of the estimated parameters

2 PROBLEM

The considered plant is a DC motor as shown in Fig. 2.1. The motor is torque or current controlled but with a tachometer feedback it can be emulated like a voltage controlled DC motor.
The motor drives an inertia. Between motor and load is a gear, which transmits the speed to lower values and increases the torque. The angular velocity is measured by a tachometer.
Friction occurs in the bearings. In general the friction is a nonlinear function of the velocity and its characteristic can e.g. look like the ones in Fig. 2.2 a+b.
If mainly the moving system is considered (that is not the start - stop operation) the characteristic can be simplified as sketched in Fig. 2.2 c.
The model of the motor can be assumed as a first order model with a nonlinear feedback due to the friction. The input signal u(t) is a voltage and the output signal y(t) the speed of the motor. The block diagram of the continuous system is shown in Fig. 2.3.
To control the system with a computer the discrete time model should be known. This is derived in [1 p. 5]. The corresponding discrete time model has the following form:

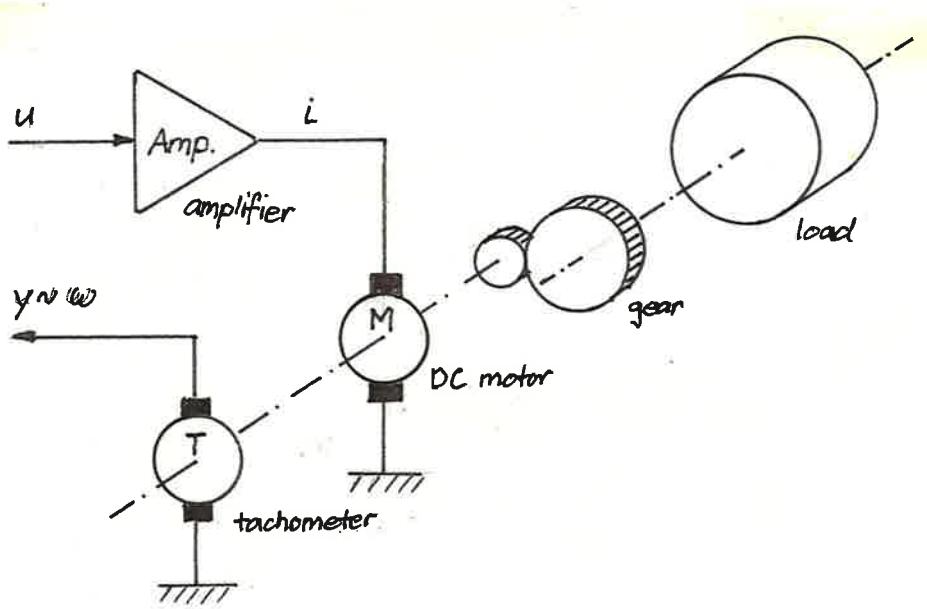


Fig. 2.1: Plant

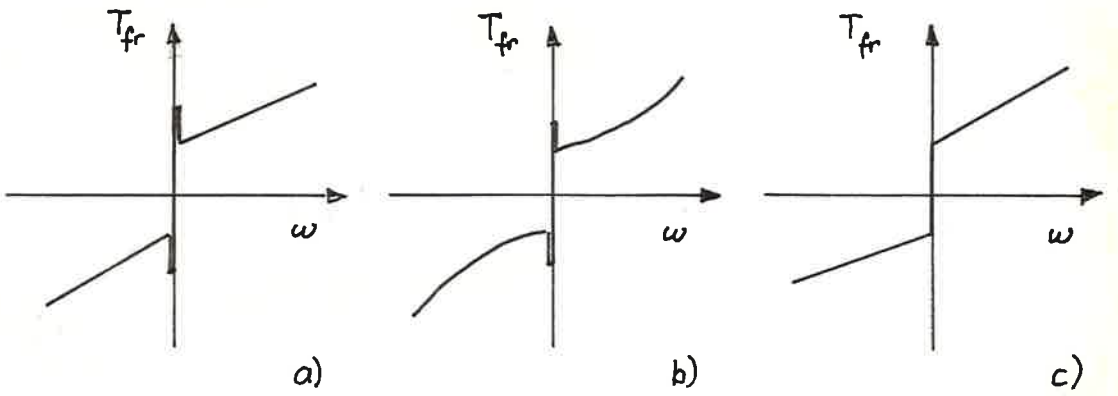


Fig. 2.2: Friction characteristics

$$y(t) = \begin{cases} (a + a1)\cdot y(t) + b\cdot u(t) - \delta 1 & \text{if } y(t) > 0 \\ (a + a2)\cdot y(t) + b\cdot u(t) - \delta 2 & \text{if } y(t) < 0 \end{cases}$$

The parameters a and b correspond to the linear model of the motor without friction whereas the parameters a1, a2, δ1, δ2 are refered to the friction.
Because in general the process parameter are not exactly known the discrete model is divided into two parts one is an approximation and the other includes the deviation to the real process.

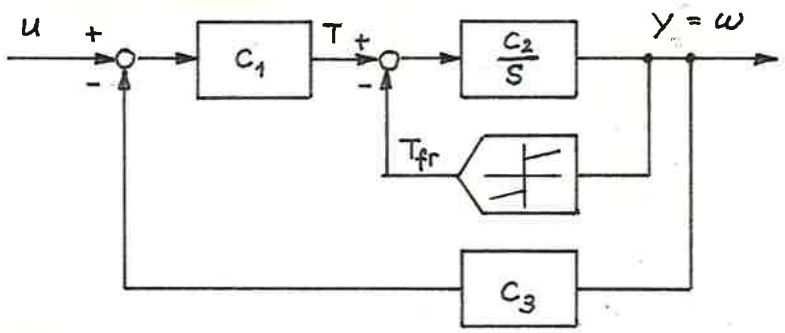


Fig. 2.3: Block diagram of the continuous system

$$y(t) = \begin{cases} (a + \tilde{a}1)\cdot y(t) + (b + \tilde{b}1)\cdot u(t) - \delta 1 & \text{if } y(t) > 0 \\ (a + \tilde{a}2)\cdot y(t) + (b + \tilde{b}2)\cdot u(t) - \delta 2 & \text{if } y(t) < 0 \end{cases}$$

The friction affects the parameters $\tilde{a}1$, $\delta 1$, $\tilde{a}2$, $\delta 2$ but they include also the deviation to the real parameter values of a. The parameters $\tilde{b}1$, $\tilde{b}2$ are introduced to correct the parameter b, since it is not exactly known.

The general idea of the adaptive compensation is the following one:

The unknown parameters are estimated by a recursive least square algorithm. The parameters $\tilde{a}1$, $\delta 1$, $\tilde{a}2$, $\delta 2$ are then used to compensate the friction. There are two sets of parameters to estimate. One set is estimated when the output y is greater then zero and the other one when y is less the zero. This allows to compensate an asymmetric friction characteristic. A description of this algorithm can be found in [8 p. 324].

A fixed linear controller is used. It is designed with the pole placement algorithm to perform a desired - input output characteristic [8 p. 221]. For this design the parameters a and b are used.

The compensation is done in the following way:

$u = u_l + u_c$ where u_l : control signal from the linear controller
u_c : compensation term

$$u_c = \frac{-1}{b + \tilde{b}n}\,(an \cdot y(t) - \delta n) \qquad \begin{cases} n = 1 \text{ if } y(t) > 0 \\ n = 2 \text{ if } y(t) < 0 \end{cases}$$

This compensation does not only compensate the friction, but also the deviation of

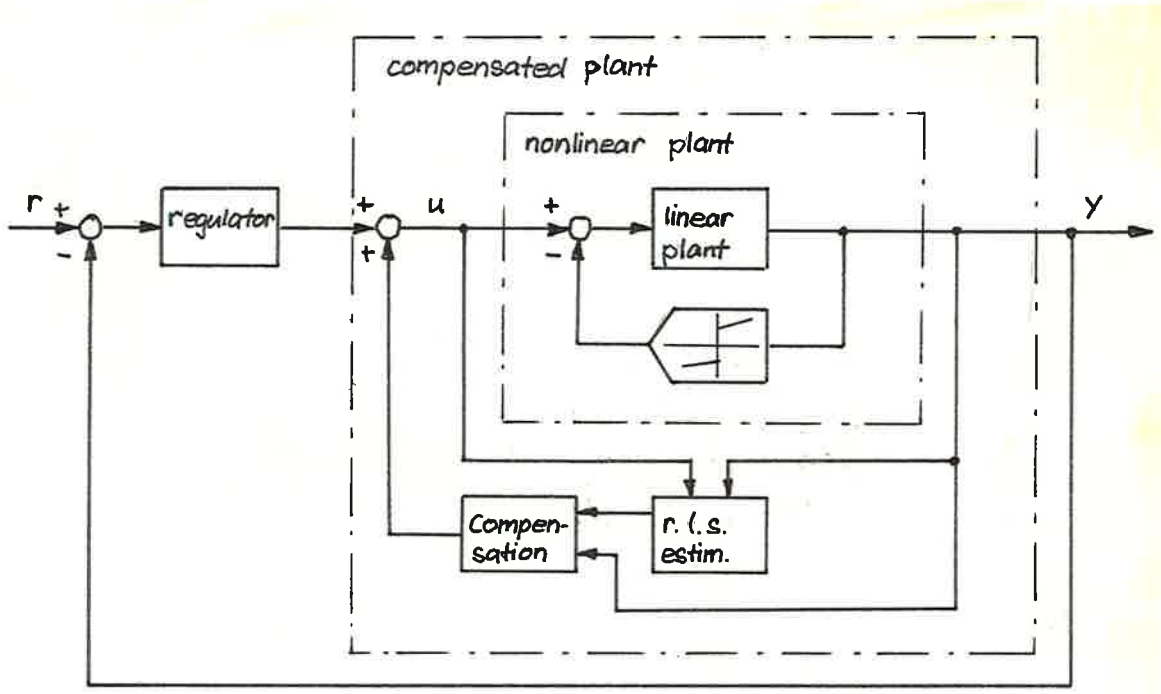


Fig. 2.4: Principle of the adaptive friction compensation

the real system to the approximated linear model described by the parameters a and b. Thus in case of convergency of the estimation the system behaves like a controlled linear system with the parameter values of the approximation. For a more detailed description of this adaptive compensation refer to [1].
The principle of this compensation is summarized in Fig. 2.4.

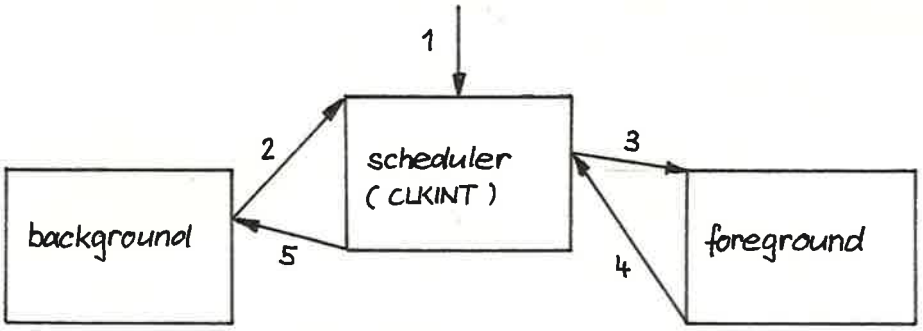
3 STARTING - POINT

The starting point of this project was the following one:

- The theoretical work was done as described in [1].

- A plant was available as shown in Fig. 2.1.

- An IBM PC could be used to implement the control algorithm. Because the DOS operating system is not designed for real-time applications some additional work had to be done. In the IBM PC a digital analog I/O board was available, but it could not be used with Pascal. Therefore some driver



1 clock interrupt
2 the foreground is interrupted by the interrupt routine
3 if the sampling period is passed the interrupt routine calls the foreground otherwise step 5 is performed directly
4 after execution of the foreground the program jumps back to the interrupt routine
5 finally the background is resumed at the point where it was interrupted

Fig. 4.1: Principle of the scheduler

routines had to be written.

- The MetaWINDOW package [5] could be used for graphic output.

4 REAL-TIME SCHEDULER

4.1 Description of the Scheduler

A normal computer program written in Pascal is performed sequentially. For real-time applications one should have the possibility to change from one task to another depending on how high the priority of these tasks are. For this implementation only a very simple scheduler is needed. It is sufficient to have a foreground - background system. In the foreground the task is implemented, which has to be performed each sampling interval. In the background some additional work can be done, which is not time critical. Normally this will be the man-machine communication. The principle of this scheduler is shown in Fig. 4.1. The scheduler must secure that the state of the background is saved after the time interrupt occured, so that the execution of the background can be properly resumed.

The time interrupts can be triggered by an external or internal clock. For simplicity the second solution was chosen. An internal clock in the IBM causes an interrupt each 0.055 sec. After this a routine is called which starting address is stored in the interrupt vector table (s. [6 p. 3-3] Normally this routine is just the return from interrupt statement (RTI). But if another starting address is loaded in the interrupt vector table a user supplied routine can be executed after each time interrupt.

To change the interrupt vector an assembler routine SCHEDULE was written. Also the interrupt routine CLKINT , which is called each time tick is written in assembly language.

The main program of the Pascal program acts as background. It is typically a loop doing some administrative work or just waiting for the time interrupt to be interrupted. The foreground is implemented as a procedure which is called by the time interrupt routine after the sample time is passed.

One of the main problem is to handle common data of the foreground and background. If the background is changing a variable and it is interrupted during this action the foreground will get a an erroneous value accessing the same variable.

This problem can be avoided by using two sets of data. In the background one changes one of the sets and as soon as this is completed a flag signals that these data can be used. If the foreground encounters that the flag is set, it copies the new data to its own data area. The principle is shown in Fig. 4.2.

This solution is a very simple one, but it has the disadvantage that the new data is not available at the first call of the foreground, because the data is copied at the end of the foreground procedure. This disadvantage could be removed by copying at the beginning of the procedure, but this should only be done if there are few common data, otherwise the delay gets to long.

A similar scheduler is described in [2]. There is one difference to mention. In that implementation the address of the global variable with the numbers of time ticks between two calls of the foreground is passed to the the scheduler. This makes it possible to change the sampling interval from the background and the foreground. In this implementation the value is passed, and therefore the sampling interval can only be changed by the background with a new call of the procedure SCHEDULE.

```
program example(input,output);

type
  comdat = record
           begin
             ..
             xy: xytype
             ..
           end;

var
  cdforegr, cdbackgr: comdat;

  cdflag,stopforegr: boolean;

procedure schedule(fg [public]: procedure, ticks: integer); extern;

procedure endsched; extern;

procedure foreground [public];

begin
  task;
  if cdflag then
  begin
    cdforegr:= cdbackgr;
    cdflag:= false;
  end;
end;

begin
  ..
  schedule(foreground, ticks);
  repeat
    ..
    cdbackgr.xy:= newvalue;
    cdflag:= true;
    ..
  until stopforegr;
  ..
  endsched;
  ..
end.
```

Fig. 4.2: Example with the scheduler

4.2 Usage

The two assembler routines SCHEDULE and ENDSCHED must be declared external in the Pascal program as shown in Fig. 4.2. The first call of SCHEDULE will save the initial interrupt vector and the foreground - background system is started. By a subsequent call of the procedure SCHEDULE the foreground routine or the sampling interval may be changed.
The foreground - background system must be stopped by a call of procedure ENDSCHED. This routine will change the interrupt vector to its initial value.
The listing of the assembler code is added in Appendix A.

4.3 Problems with the Scheduler

A problem was encountered using the scheduler. It was not possible to use the write, writeln and read, readln procedures in connection with the digital and analog I/O board and the driver routines described in Chap. 5.
When this was done the I/O board did not work properly that is either it did not get ready or the results were completely useless.

5. ANALOG AND DIGITAL INPUT / OUTPUT

5.1 Description of the Driver Routines

The analog signals of the process must be converted to digital numbers before they can be used in the computer. Conversely the computed output signals are digital numbers which must be converted to analog signals. In the IBM PC this is done with help of a single board analog and digital I/O system [3]. There are 16 channels for analog inputs and two channels for analog outputs available.
To use this board with Pascal some driver must be written. The MICROSOFT Pascal [4] allows to use units which can be compiled separately from the main program. Thus the three driver routines are collected in a unit. This unit uses four external routines which are written in assembler. This routines transfer commands and data between the Pascal program and the I/O board. The object code of the unit and the assembler routines must be added when linking the program. The listing of the assembly code is shown in Appendix B.
The three Pascal routines in the unit ADDAB are briefly described below.

Procedure INITADDA

A call of this procedure initializes the I/O board. All the activities are stopped and the two analog outputs are set to -10 Volts.

Function ADIN

This function yields the values of the specified analog input channel. There are 16 channels (0 to 15).
The range of the analog input may be between -10 and 10 volts and this voltages

```
{$include: 'addab.int'}

program addatest(input,output);

uses addab(adin, daout, initadda);

var
  val: real;

begin
  initadda;            {initializes the I/O baord}
  val:= adin(0);       {reads value form input channel 0}
  daout(0,val);        {sets analog output channel 0 to
                        the value of the analog input}
end.
```

Fig. 5.1: Program with analog input and output

are converted to real numbers in the range -1.0 to 1.0. The resolution is 12 bits, which corresponds to 5 mV for the range of -10 to 10 Volts.
A single A/D conversion takes about 3 ms.

Procedure DAOUT

With this procedure one of the two analog output channels (0 or 1) may be set. The real parameter outval must be in the range -1.0 to 1.0 and this number is converted to an output voltage within the limits -10 and 10 Volts. The analog output channels have also a resolution of 12 bits.
A D/A conversion takes about 3 ms.

5.2 Usage

A unit in MICROSOFT Pascal consists of two parts, that is the interface and the implementation. The interface must be included to at the very beginning of the source file to make sure that the routines are known when compiling the program.
The object files of the unit and the one of the assembly routines must be added when linking the program.
An example of a short program using the I/O board is shown in Fig. 5.1.

6 THE PROGRAM AFRICO

The Program for this adaptive friction compensation should fulfil the following specifications:

- The man - machine interface should be interactive and therefore easy to use.

- After an experiment the main variables should be graphically displayed.

- The minimal sampling rate of 0.055 sec should be possible to use. This means, that the foreground procedure with the control and estimation task should not take more time then 55 ms.

- The program should allow to make different experiments:
  * controller without friction compensation
  * controller with fixed friction compensation
  * controller with adaptive friction compensation

The program is divided into four parts:

1. Initialization of the program
2. Modification of the parameters
3. Experiment
4. Evaluation of the experiment

The possible flows through the program are shown in Fig. 6.1.

Initialization of an Experiment

In this first part the I/O board and the graphic system is initialized. Then the default values are read from a specified file. Thus one can have different files with default values for special experiments. This file should be of the form like the one shown in Appendix C.

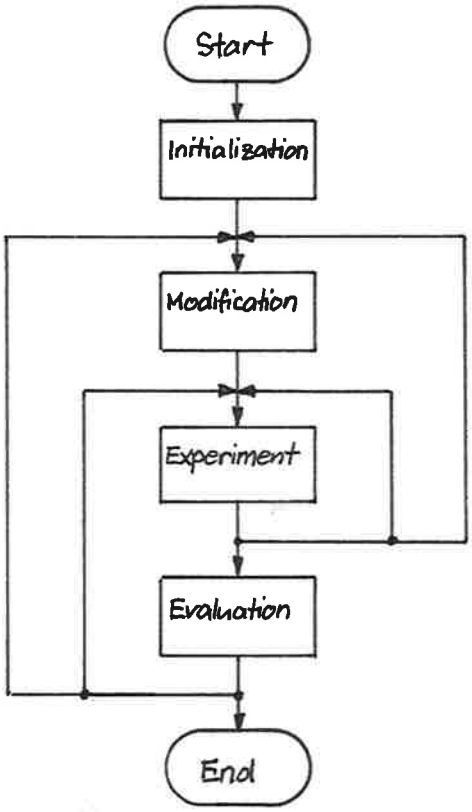


Fig. 6.1: Possible flows through the program AFRICO

Modification of the Parameters

In this part the parameters can be changed interactively. The menu for the modifications is added in Appendix D.

Experiment

This is the part where the foreground - background system is running. The background checks continuously whether the key F1 is pressed. Striking this key stops the controller.

Evaluation of the Experiment

During the experiment the traces of some variables are stored. These traces can be graphed in this part. The menu to choose between these variables is shown in

Appendix D.

The foreground has the following sequence:

1. analog input of the reference signal r(t) and the output signal y(t)
2. computation of the control signal u(t) with help of the estimated parameters from the previous call of the foreground
3. analog output of the control signal u(t)
4. recursive least square algorithm
5. store the variables, which may be plotted later
6. preparation of the variables used for the compensation at the next call of the foreground
7. update of the variables

This sequence has the advantage, that the delay between the call of the foreground and the output of the control signal can be neglected. To use the new estimates for the compensation the estimation has to be done before the computation of the output signal u(t). But since the estimation needs the most computing time in the foreground, the delay would increase.
Since the controller includes integral action, the windup problem had to be considered, and precautions were taken to avoid this phenomena.

The listing of this program is added in Appendix C.

To estimate initial values for the program AFRICO the program IDENT was written. In the main parts it is equivalent to the program AFRICO, but in the foreground the controller is omitted. The input signal is pluged in directly into the process and the parameters $\tilde{a}1$, $\tilde{b}1$, $\delta 1$, $\tilde{a}2$, $\tilde{b}2$, $\delta 2$ are estimated. Thus the real values of the discrete time model can be determined:

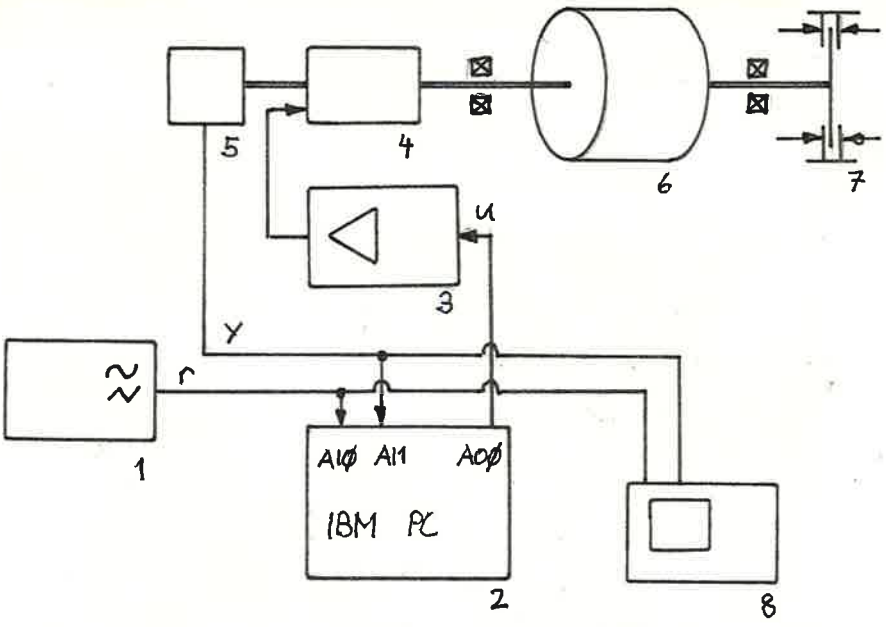
$$y(t) = \begin{cases} a1_r \cdot y(t) + b1_r \cdot u(t) - \delta 1_r & \text{if } y(t) > 0 \\ a2_r \cdot y(t) + b2_r \cdot u(t) - \delta 2_r & \text{if } y(t) < 0 \end{cases}$$

where

$$a1_r = a + \tilde{a1}; \quad b1_r = b + \tilde{b1}; \quad \delta 1_r = \delta 1$$

$$a2_r = a + \tilde{a2}; \quad b2_r = b + \tilde{b2}; \quad \delta 2_r = \delta 2$$

A listing of the source code is added in Appendix E.



1 signal generator
2 IBM PC
AIO: analog input channel 0
AI1: analog input channel 1
AOO: analog output channel 0
3 amplifier
4 DC motor
5 tachometer
6 load
7 break to add friction

Fig. 7.1: Arrangement of the devices

7 RESULTS

The arrangement of the devices used to perform the following experiments is shown in Fig. 7.1.

7.1 Open-Loop System

To get starting values for the controller design the step response of the open-loop system was determined (s. Fig. 7.2). With this measurement an approximation of the parameters a and b can be calculated.

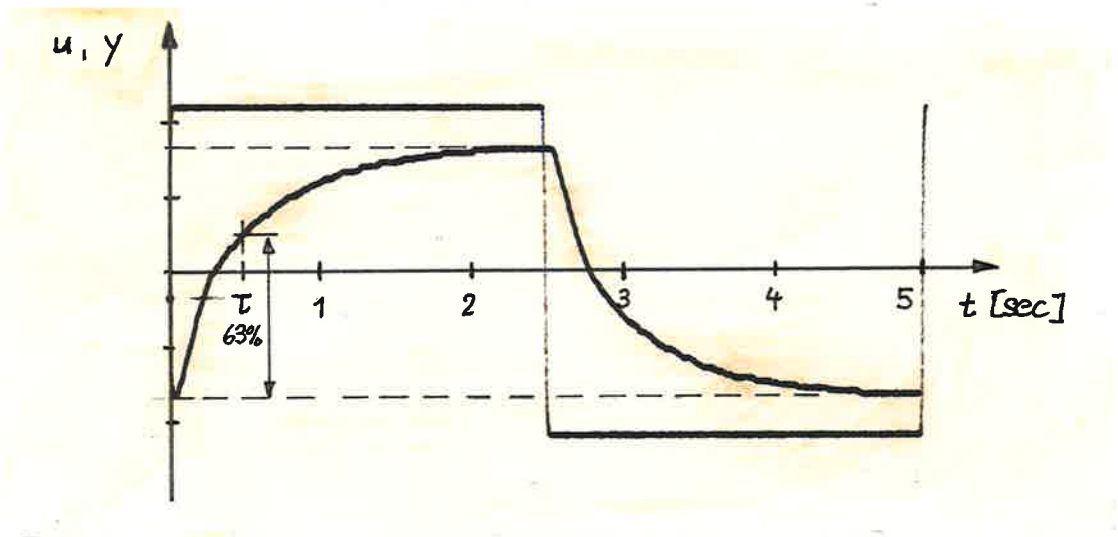


Fig. 7.2: Step response of the open-loop system

The linear approximation of the continuous time system is:

$$G(s) = \frac{\alpha}{\tau \cdot s + 1} \quad \text{where} \quad \alpha = 1.3, \quad \tau = 0.5 \text{ sec}$$

thus the discrete time system is

$$H(z) = \frac{b}{z + a} \quad \text{with} \quad a = -e^{-T/\tau} = -e^{-0.055/0.5} = -0.9$$

$$b = \alpha \cdot (1 - e^{-T/\tau}) = 1.3$$

7.2 Closed-Loop System without Compensation

The approximation was used to design a controller for the closed-loop system without compensation. Two controllers were used to perform tests. They are determined by the following parameters:

	controller 1	controller 2
closed-loop polynominal: $A_m(z) = z - am$; am =	0.9	0.75
observer polynominal: $A_o(z) = z - a0$; a0 =	0.6	0.6

The result of the step response with controller 1 and without compensation is shown in Fig. 7.3. The sampling rate is 0.055 sec.

The trace in Fig. 7.3 shows, that the step response is not completely smooth as it should be with a linear system. Especially in the cross-over point a bend can be

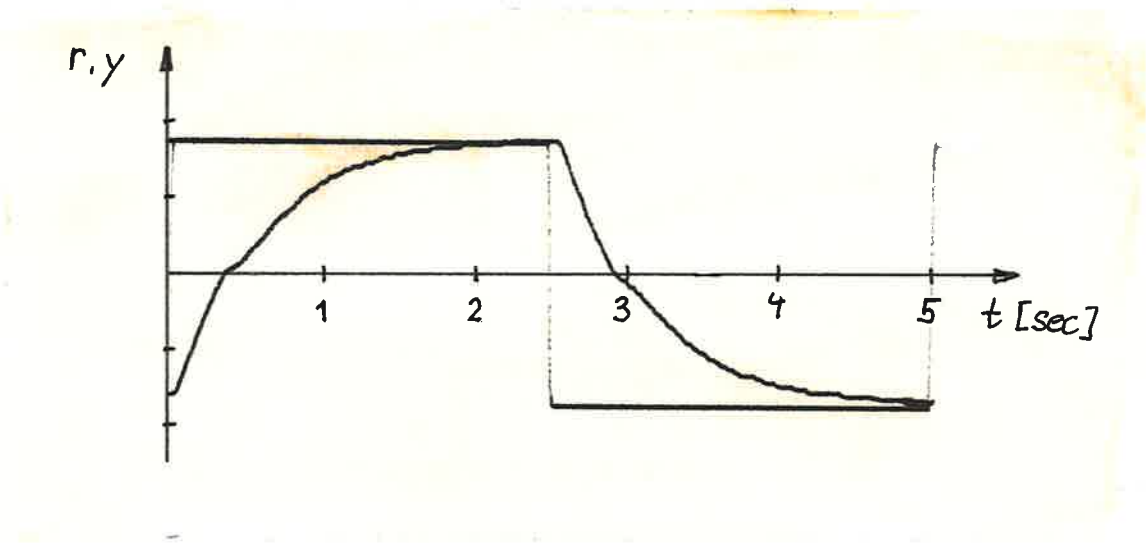


Fig. 7.3: Closed-loop system without compensation

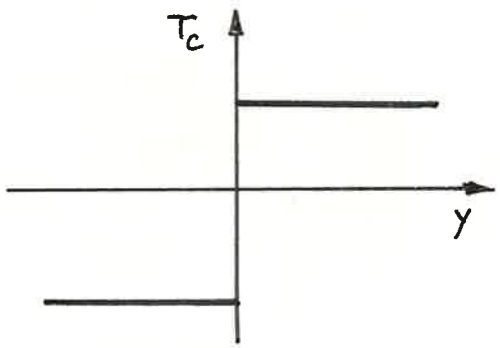


Fig. 7.4: Fixed compensation

seen. This asymmetric behaviour is do to the asymmetric friction.
The static error vanishes because the controller includes an integral action.

7.3 Closed-Loop System with fixed Compensation

To improve the behaviour of the system the nonlinearity can be compensated with a fixed compensation. This is only done for the constant part of the friction. The torque to compensate the friction is shown in Fig. 7.4. It may be different for positive and negative velocities. An approximation of the parameters for this compensation can be obtained by measuring the moment needed to move the system or by an off-line identification.
The step response with controller 1 is shown in Fig. 7.5. It is obvious that the

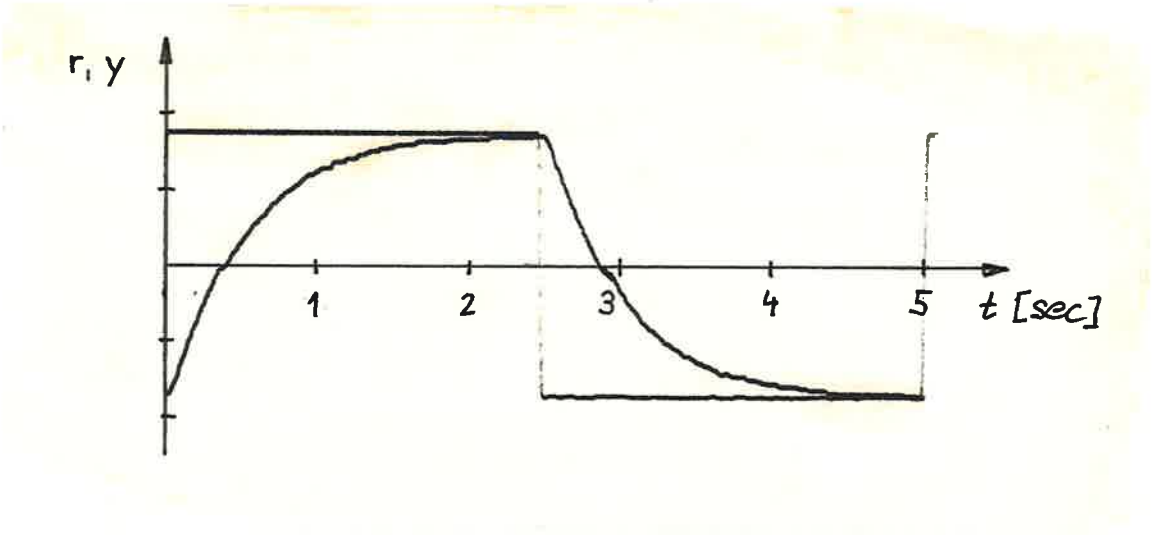


Fig. 7.5: Step response with fixed compensation

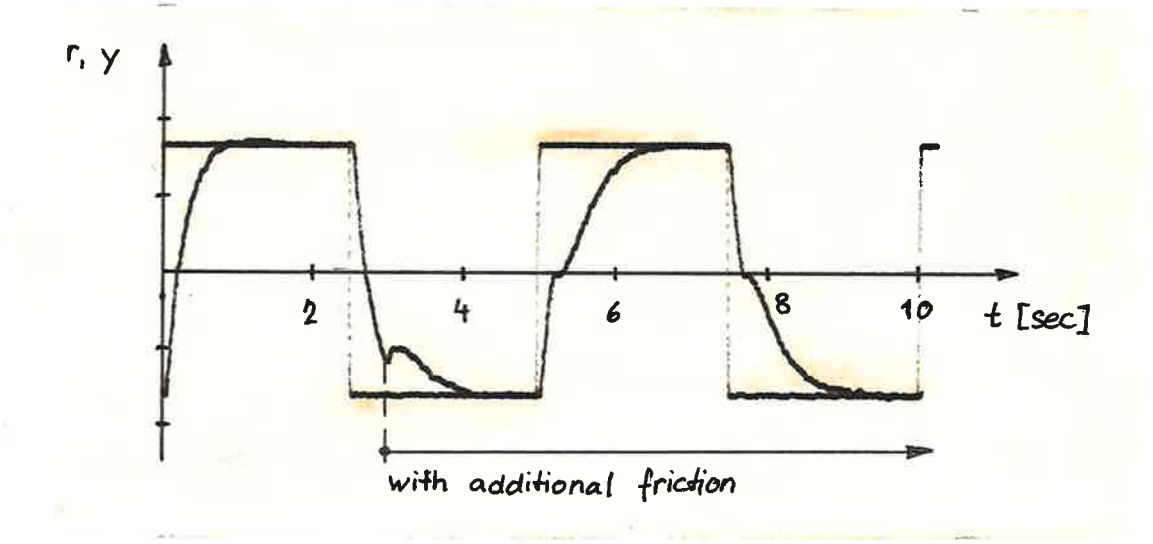


Fig. 7.6: Fixed compensation with changing friction

bend in the cross-over point became smaller.

This compensation yields fairly good results if the viscous friction is only small and the constant part of the friction does not change.

Fig. 7.6 shows what happens, if the friction changes. A break increases the friction three times. The step response after this change is different and dependent on the friction. In this example the controller 2 was used.

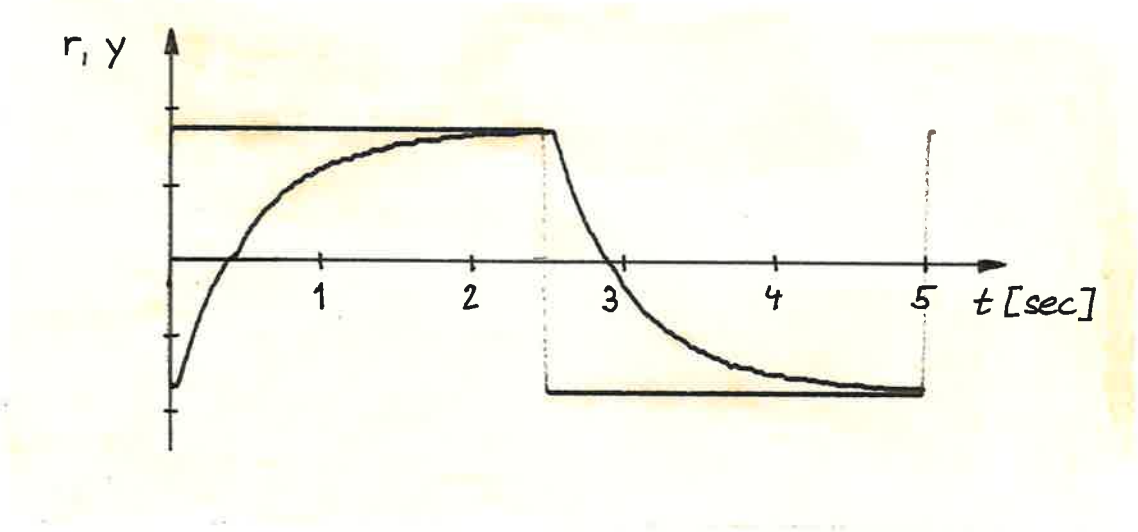


Fig. 7.7: Step response of the adaptive system

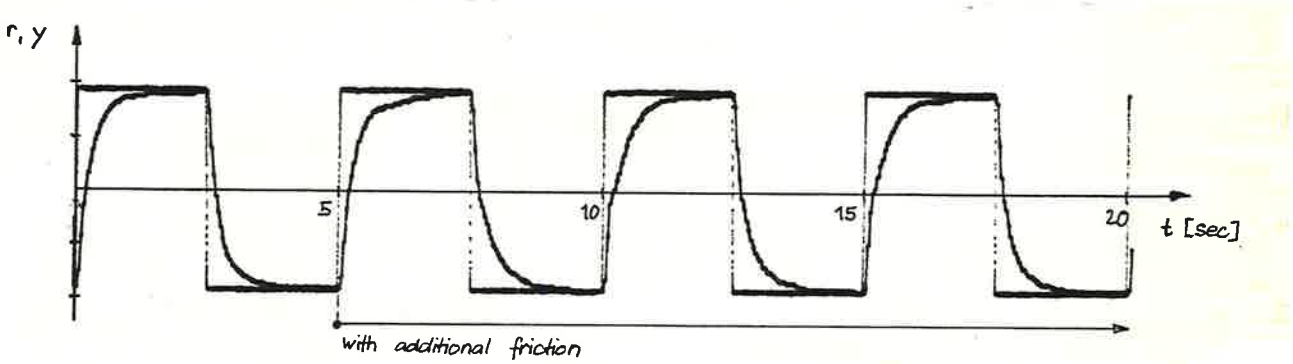


Fig. 7.8: Adaptive compensation with changing friction

7.4 Closed-Loop System with adaptive Compensation

To compensate a slowly varying friction the compensation has to be done adaptive. The step response of the adaptive system with controller 1 is shown in Fig. 7.7. The trace is recorded after a short time of adaptation.

Fig. 7.8 shows the step response with a change of the friction using controller 2. It can easily be seen, that the adaptation is working well. 10 sec after adding the break the step response has nearly the same shape as before the changing of the friction. The time needed for the adaptation is a function of the richness of the input signal and the forgetting factor.

The advantage of the adaptive system can be noticed even more obviously with a ramp as input signal. Fig. 7.9 shows a comparison of a fixed and an adaptive compensation.

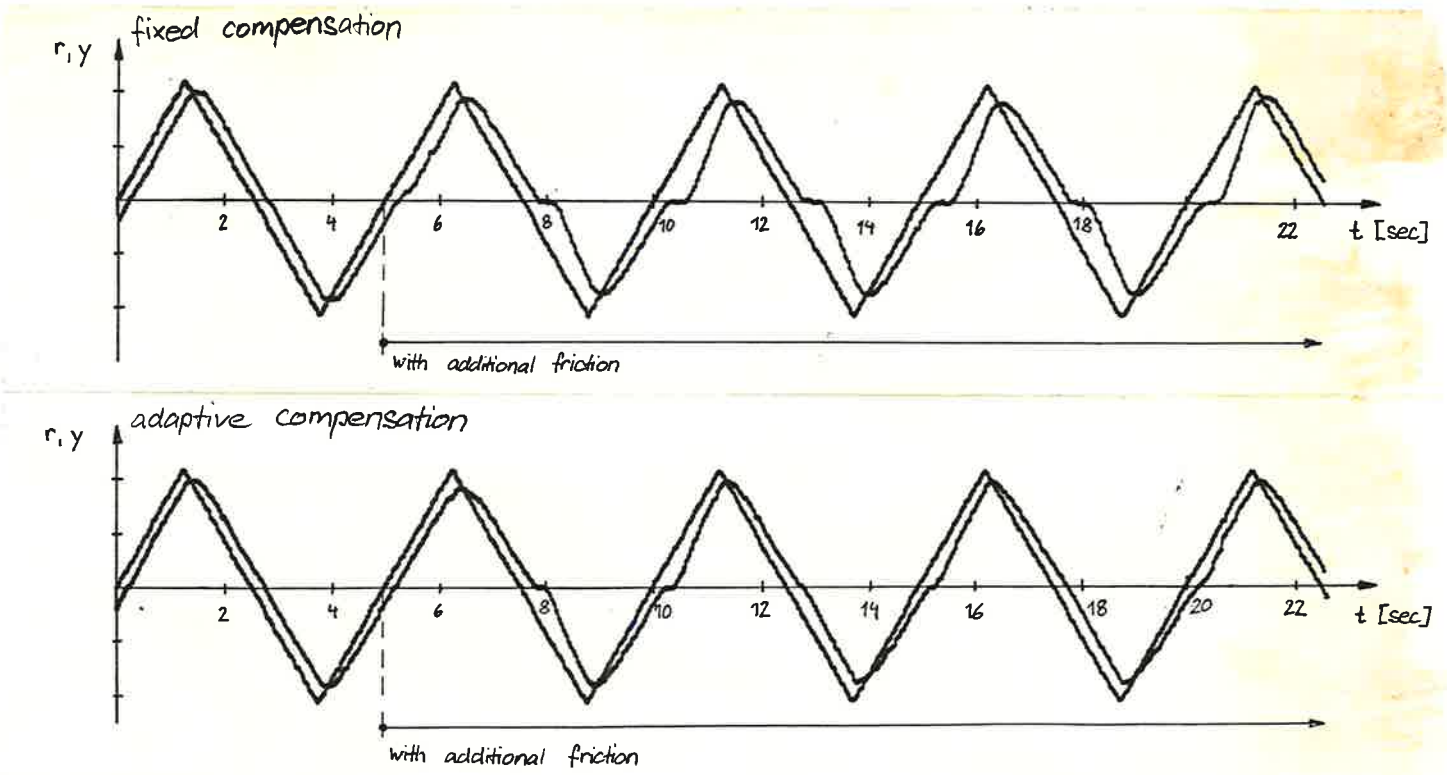


Fig. 7.9: Comparison of fixed and adaptive compensation

If the fixed compensation uses the right values, the ramp is quite smooth. When the friction is increased, the output signal is deformed.
In the adaptive system the output signal is also deformed first, but already after 5 sec one can see that the signal recovers. After some more periods there is no difference of the trace compared with the one before adding the friction.

8 CONCLUSIONS

This real-time implementation makes use of a microcomputer without a special real-time operating system. This causes some problems, because one has to know much more about the hardware, than for the normal usage. There are still some points, which could be solved in a more elegant way:

- When the scheduler is active with analog input and output in the foreground, it is impossible to do input or output from the keyboard resp. screen.

A solution should be found to make input and output possible in order to perform modifications, while the real-time activities are running.

- By using an external time interrupt with more time ticks per second the minimal sample interval could be diminished. Thus the scheduler could also be used for faster processes.

- The analog input/output board is rather slow.

- It would be an advantage to be able to make screencopies of the graphics. In principle this should be possible as described in [5 p. 91].

The results presented in Chap. 7 show the advantage of the adaptive friction compensation. The control algorithm can not only track changing friction, but also variation in the dynamics of the system e.g. additional load or change of the electrical part of the motor.

Some care has to be taken for control of small speed or stillstand. If the velocity changes from one direction to the other, the set of parameters for the compensation is changed. If the estimated parameters are not exactly the right ones or the system is disturbed by noise, chattering may occur.

This adaptive friction compensation can be used for DC motor systems, where a high performance under time-varying conditions is demanded. Further the estimation algorithm could also be used to watch over a DC motor system. It can be detected, when the friction exceeds critical values. If this happens, there is probably something wrong in the system e.g. a bearing is worn out or something is inhibited.

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[5] MetaWINDOW
Users Guide for the IBM PC

[6] IBM PC
Technical Reference

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Computer Controlled Systems
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APPENDICES

A: Source Code of the Scheduler

B: Source Code of the analog Input/Output Routines

C: Source Code of the Program AFRICO

D: Menus of the Program AFRICO

E: Source Code of the Program IDENT

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COMMENT *

PROLOG - SCHEDULER
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PURPOSE:
   This assembler program can be used together with a MICROSOFT-Pascal
   program in order to get a simple real-time scheduler.
   The Pascal program is devided into the foreground (FG) and the back-
   ground (BG). The main program acts as background whereas the foreground
   is declared as a procedure which is called each sampling time.
   The assembler program handles the initialization, the time interrupts,
   calls of the foreground routine at each sampling intervaland the
   termination of the real-time scheduler.
   The time interrupts are caused by a routine in the ROM which causes
   an interrupt 1CH. This is done 18.2 times a second or each 0.055 sec.
   The interrupt handler will invoke a user routine.
   Therefore the address of the starting point must be placed in the
   table (address 0000:0070).

USAGE:
   Two external procedures must be declared in the Pascal program:

     procedure SCHEDULE(procedure FG [public]; TICKS: integer) extern;

     procedure ENDSCHED; extern;

   With a call of the procedure SCHEDULE the scheduler is initialized.
   Passed parameters are the foreground procedure (which must be declared
   'public') and the number of time ticks between two calls of the fore-
   ground (ticks = sample time [sec] multiplied by 18.2)
   The foreground procedure or the sample time can be changed by recall
   the procedure SCHEDULE.
   The scheduler should be stopped by a call of the procedure ENDSCHED.
   In this routine the interrupt vector of interrupt 1CH is set to its
   initial value.

DATE:
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AUTHOR:
   Konrad Braun    *


DATAS    SEGMENT PUBLIC
DSPAS    DW          ?          ; storage for Pascal CS
FLAGIP   DW          0          ; flag variable to indicate
                                ; that inital interrupt
                                ; pointer is stored
INTPTR   DD          ?          ; storage for initial inter-
                                ; rupt pointer
ADDRFG   DD          ?          ; storage for the address of
                                ; the foreground procedure
TICKS    DW          ?          ; number of ticks between two
                                ; calls of the foreground
LAG      DW          0          ; variable to store a request
INCT     DW          ?          ; variable to count the time
                                ; ticks
ACTIVE   DW          0          ; variable to indicate that
```

```
                                        ; the foreground is active
DATAS   ENDS

DGROUP  GROUP   DATAS
        ASSUME  CS:SCHEDS,DS:DGROUP
        ASSUME  SS:DGROUP,ES:DGROUP

SCHEDS  SEGMENT 'CODE'

        PUBLIC  SCHEDULE
SCHEDULE PROC FAR
        PUSH    BP                      ; save BP and DS registers,
        MOV     BP,SP                   ; the other registers may
        PUSH    DS                      ; changed without to affect
                                        ; the Pascal program
        CLI                             ; disable interrupt
        MOV     AL,01H
        OUT     021H,AL

        MOV     BX,DS
        MOV     AX,DGROUP
        MOV     DS,AX                   ; set DS to DGROUP
        MOV     DSPAS,BX                ; save DS register of the
        SUB     AX,AX                   ; Pascal program
        MOV     ES,AX                   ; use the extra-segment re-
        MOV     BX,070H                 ; gister to set interr. vector
        CMP     FLAGIP,0
        JG      IPSET                   ; if FLAGIP > 0 goto IPSET
        MOV     AX,ES:[BX]              ;   else save initial inter-
        MOV     INTPTR,AX               ;   rupt vector
        MOV     AX,ES:[BX+2]
        MOV     INTPTR+2,AX
        MOV     ES:WORD PTR [BX],OFFSET CLKINT
                                        ;   set new interrupt vector
        MOV     ES:[BX+2],CS            ;   procedure CLKINT
        INC     FLAGIP                  ;   set FLAGIP
IPSET:
        MOV     BX,[BP+10]
        MOV     AX,[BX+2]               ; save code segment of the
        MOV     ADDRFG+2,AX             ; new foreground procedure
        MOV     AX,[BX]                 ; save offset of the new
        MOV     ADDRFG,AX               ; foreground procedure
        MOV     AX,[BP+6]               ; save number of ticks be-
        MOV     TICKS,AX                ; tween two calls
        MOV     INCT,1                  ; INCT := 1
        MOV     LAG,0                   ; LAG := 0
        POP     DS
        POP     BP                      ; restore DS and BP
        MOV     AL,0
        OUT     021H,AL
        STI                             ; inable interrupt
        RET     6                       ; return, clear stack
SCHEDULE ENDP

CLKINT  PROC    FAR
        CLI                             ; disable interrupts
        PUSH    BP
        MOV     BP,SP
        PUSH    DS
```

```
        PUSH   AX                       ; save BP,DS, and AX reg.
        MOV    AX,DGROUP
        MOV    DS,AX                    ; set DS to DGROUP
        CMP    TICKS,0
        JG     RUN                      ; if TICKS > 0 goto RUN
        MOV    INCT,1                   ;   else INCT :=1
        MOV    LAG,0                    ;     LAG := 0
        JMP    RETURN                   ;     goto RETURN
RUN:
        DEC    INCT                     ; INCT := INCT - 1
        JG     RETURN                   ; if INCT > 0 goto RETURN
        MOV    AX,TICKS                 ;  else
        MOV    INCT,AX                  ;  INCT := TICKS
        INC    LAG                      ;  LAG := LAG + 1
        CMP    ACTIVE,0
        JNZ    RETURN                   ;  if ACTIVE > 0 goto RETURN
        INC    ACTIVE                   ;   else
        PUSH   BX                       ;   ACTIVE := ACTIVE + 1
        PUSH   CX
        PUSH   DX
        PUSH   SI
        PUSH   DI
        PUSH   ES                       ;   save registers
LOOP1:
        MOV    LAG,0                    ;   clear LAG
        PUSH   DS                       ;   save DS in the stack
        MOV    AX,DGROUP
        MOV    ES,AX                    ;   set ES to DGROUP
        MOV    DS,DSPAS                 ;   set DS to the data segment
                                        ;   in the Pascal program
        STI                             ;   inable interrupts
        CALL   ES:ADDRFG                ;   call foreground proc.
        CLI                             ;   disable interrupts
        POP    DS                       ;   restore DS
        CMP    LAG,0
        JG     LOOP1                    ;   if LAG > 0 loop to LOOP1
        MOV    ACTIVE,0                 ;   else
        POP    ES                       ;    ACTIVE := 0
        POP    DI
        POP    SI
        POP    DX
        POP    CX
        POP    BX                       ;    restore registers
RETURN:
        PUSHF                           ; call initial interrupt
        CALL   INTPTR                   ; routine
        POP    AX
        POP    DS
        POP    BP                       ; restore AX, DS, BP
        IRET                            ; return from interrupt
CLKINT  ENDP

        PUBLIC  ENDSCHED
ENDSCHED PROC  FAR
        PUSH   BP
        MOV    BP,SP
        PUSH   DS                        ; save BP and DS reg.
        CLI                              ; disable interrupt
        MOV    AL,01H
```

```
        OUT     021H,AL
        MOV     AX,DGROUP
        MOV     DS,AX                   ; set DS to DGROUP
        SUB     AX,AX
        MOV     ES,AX                   ; ES := 0
        MOV     BX,070H
        MOV     AX,INTPTR
        MOV     ES:[BX],AX
        MOV     AX,INTPTR+2             ; reset interrupt vector to
        MOV     ES:[BX+2],AX            ; inital value
        MOV     FLAGIP,0                ; clear flagip
        MOV     AL,0
        OUT     021H,AL
        STI                             ; enable interrupt
        POP     DS
        POP     BP                      ; restor DS and BP
        RET                             ; return
ENDSCHED ENDP
SCHEDS  ENDS
        END
```

```
interface (1);

unit addab(adin,daout,initadda);

function adin(channel: integer): real;
procedure daout(channel: integer; outval: real);
procedure initadda;

begin
end;
```

```
{$include: 'addab.int'}

implementation of addab;

procedure outcom(com: integer); extern;

procedure outdata(data: integer); extern;

procedure indata(var data: integer); extern;

procedure initio; extern;

function adin;
 const cadim=12; gain=0;
 var xlow, xhigh: integer;
 begin
  if (Channel)=0) and (Channel(=15) then
  begin
   outcom(cadim);
   outdata(gain);
   outdata(channel);
   indata(xlow);
   indata(xhigh);
   adin:= float(xhigh*256+xlow)/2048.0-1.0
  end
  else
   adin:= 0.0;
 end;

procedure daout;
 const vmax=0.9995118; cdaim=8;
 var x, xhigh, xlow: integer;
 begin
  if (channel=0) OR (channel=1) then
  begin
   if outval)vmax then outval:=vmax
   else if outval(-vmax then outval:=-vmax;
   outval:=outval+1.0;
   x:=trunc(outval*2048.0+0.5);
   xhigh:= x div 256;
   xlow:= x mod 256;
   outcom(cdaim);
   outdata(channel);
   outdata(xlow);
   outdata(xhigh)
  end
 end;

procedure initadda;
 const command=16#2ed; datareg=16#2ec;
 var val: integer;
 begin
  initio;
  outcom(1);
 end;

begin
end.
```

```
COMMENT *

PROLOG - IOPROCA
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PURPUSE:
   These assembler routines are used in MICROSOFT-Pascal as external
   procedures.
   OUTCOM transfers a command to the single board analog and digital
   i/o system, OUTDATA transfers a data byte to the board and INDATA
   reads a byte from the board.
   The procedure INITIO is used for initialization.

USAGE:
   The four external procedures must be declared in the Pascal program
   in the following way:

      procedure OUTCOM(COM: integer); extern;

      procedure OUTDATA(DATA: integer); extern;

      procedure INDATA(var DATA: integer); extern;

      procedure INITIO; extern;

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AUTHOR:
   Konrad Braun          *


STATUS          EQU   02EDH
COMMAND         EQU   02EDH
DATAREG         EQU   02ECH
READY           EQU   04H
DATAINFULL      EQU   02H
READREADY       EQU   05H


          ASSUME CS:IOPROCS

IOPROCS   SEGMENT  'CODE'

          PUBLIC OUTCOM
OUTCOM    PROC   FAR
          PUSH   BP             ; save BP register
          MOV    BP,SP          ; set base pointer
          MOV    DX,STATUS      ; set port address
LOOP1:
          IN     AL,DX          ; read status byte from the board
          AND    AL,READY
          JZ     LOOP1          ; loop until ready bit set
          MOV    AX,[BP+6]      ; mov command to the AX register
          MOV    DX,COMMAND     ; set port address
          OUT    DX,AL          ; transfere command to port
          POP    BP             ; restore BP
          RET    2              ; return, clear stack
OUTCOM    ENDP
```

```
        PUBLIC OUTDATA
OUTDATA PROC  FAR
        PUSH  BP            ; save BP register
        MOV   BP,SP         ; set base pointer
        MOV   DX,STATUS     ; set port address
LOOP2:
        IN    AL,DX         ; read status byte from the board
        AND   AL,DATAINFULL
        JG    LOOP2         ; loop until datainfull bit cleard
        MOV   AX,[BP+6]     ; mov data to AX register
        MOV   DX,DATAREG    ; set port address
        OUT   DX,AL         ; transfere data to port
        POP   BP            ; restore BP register
        RET   2             ; return, clear stack
OUTDATA ENDP

        PUBLIC INDATA
INDATA  PROC  FAR
        PUSH  BP            ; save BP register
        MOV   BP,SP         ; set base pointer
        MOV   DX,STATUS     ; set port address
LOOP3:
        IN    AL,DX         ; read status byte from the board
        AND   AL,READREADY
        JZ    LOOP3         ; loop until readready bit set
        MOV   DI,[BP+6]     ; set DI register
        MOV   DX,DATAREG    ; set port address
        SUB   AX,AX         ; clear AX register
        IN    AL,DX         ; transfere byte from port to AL
        MOV   [DI],AX       ; mov ax register to the variable
        POP   BP            ; restore BP
        RET   2             ; return, clear stack
INDATA  ENDP

        PUBLIC INITIO
INITIO  PROC  FAR
        MOV   DX,COMMAND    ; set port address
        MOV   AL,15
        OUT   DX,AL         ; transfere stop command to baord
        MOV   DX,DATAREG
        IN    AX,DX         ; read data form the baord to clear it
        RET                 ; return
INITIO  ENDP

IOPROCS ENDS

        END
```

```
{-----------------------------------------------------------------------

PROLOG - AFRICO
---------------

PURPOSE:

   This program implements an adaptive friction compensation. It uses
   the routine SCHEDULE to get a simple real-time system. There are
   a foreground and a background. The foreground is called each sampling
   interval. The control algorithm is programed in the foreground and
   the man-machine interface is done by the backgrond.


USAGE:

   The reference signal from a signal generator should be connected with
   the analog input channel 0, the output of the process with analog
   input channel 1. The analog output channel 0 puts out the control
   signal and should be connected to the process.
   The program is expected to be easy to use. After typing the name of
   the program a file with the default values must be specified.
   This file is a text file of the following form (the comments are
   not needed):

     1                 ; ticks (number of ticks between calls of foregr.)
     0.5               ; ouint (interval between two points of the plots)
     0.8 0.11          ; a, b  (parameters of the discrete time model)
     0.99              ; lam   (forgetting factor)
     0.75              ; am    (closed loop parameter)
     0.6               ; a0    (observer polynominal)
     0.0 0.0 -0.1      ; tef1  (values for the fixed compensation)
     0.0 0.0 0.1       ; tef2  (values for the fixed compensation)
     1.0 -1.0          ; umax, umin  (control signal limitations)

   The rest of the program is self-explicable.

DATE:

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AUTHOR:

   Konrad Braun

-----------------------------------------------------------------------}

{$include: 'addab.int'}

program test4(input,output,defval);

uses addab(adin,daout,initadda);

const   n=3;
        x0= 99;      y0= 110;     xmax= 500;  ymax=150;
```

```
        maxpoint= 200;

type    vec1=   array [1..n] of real;

        mat1=   array [1..n,1..n] of real;

{$include: 'grconst.inc'}

var     defval: text;

        i,j,ticks,actual,strtp,maxpl,it,nout          : integer;

        a,b,a0,am,umax,umin,
        r,rb,rbd1,y,yd1,u,ud1,ul,uld1,e,
        t,sampint,tscale,yscale,outint,
        atilf1,btilf1,delf1,atilf2,btilf2,delf2,
        lam,s0,s1,r0,pf                               : real;

        phi,te1,te1d1,te2,te2d1,tef1,tef2,
        tec1d1,tec2d1                                 : vec1;

        p1,p1d1,p2,p2d1                               : mat1;

        stopprog,stopplt,startplt,moddone,
        startctrl,stopctrl,stopgraf,plotgrf           : boolean;

        comp                                          : (none, fix, adptv);

        updflag                                       : (pos, neg, nul);

        graphx,graphy                 : array[1..maxpoint] of integer;

        stot,stoy,stou,stor,stoe,
        stoatil1,stobtil1,stodel1,
        stoatil2,stobtil2,stodel2,
        plotarr                       : array[0..maxpoint-1] of real;

        plotvar                                       : string(20);

        lblx1,lblx2,lbly1,lbly2                       : lstring(9);

        evnt                                          : event;

value   updflag:= nul; comp:= fix;

{$include: 'grextrn.inc'}


procedure schedule(procedure fg [public]; ticks: integer); extern;


procedure endsched; extern;


function sign(x: real): integer;

begin
 sign:= ord(x>0.0)-ord(x<0.0)
end;
```

```
procedure foregnd1 [public];

var     d1,t1,t2: real;

        estim: boolean;


procedure control;

begin
 rb:= pf*r;
 ul:= uld1+(rb-a0*rbd1-s0*y-s1*yd1)/r0;
 if (y)0.0) or ((y=0.0) and (ul)0.0)) then
 begin
  t1:= tec1d1[1]*y+tec1d1[3]; t2:= b+tec1d1[2];
  u:= (b*ul-t1)/t2;
 end
 else if (y(0.0) or ((y=0.0) and (ul(0.0)) then
 begin
  t1:= tec2d1[1]*y+tec2d1[3]; t2:= b+tec2d1[2];
  u:= (b*ul-t1)/t2;
 end
 else
 begin
  t1:= 0.0; t2:= 0.0;
  u:= 0.0;
 end;
 if u)umax then u:= umax
 else if u(umin then u:= umin;
end;


procedure rls;

var   s1: real;
      kd1,v1: vec1;
      m1,m2: mat1;


procedure vsmul(var v: vec1; var s: real; var res: vec1);

var i: integer;

begin
 for i:= 1 to n do res[i]:= v[i]*s;
end;


procedure vvtmul(var v1,v2: vec1; var res: mat1);

var i,j: integer;

begin
 for i:= 1 to n do
  for j:= 1 to n do  res[i,j]:= v1[i]*v2[j];
end;
```

```
procedure vtvmul(var v1,v2: vec1; var res: real);

var i: integer;

begin
 res:= 0.0;
 for i:= 1 to n do  res:= res+v1[i]*v2[i];
end;


procedure mvmul(var m: mat1; var v,res: vec1);

var i,j: integer;

begin
 for i:= 1 to n do
 begin
  res[i]:= 0.0;
  for j:= 1 to n do  res[i]:= res[i]+m[i,j]*v[j];
 end
end;


procedure mmmul(var m1,m2,res: mat1);

var i,j,k: integer;

begin
 for i:= 1 to n do
 begin
  for j:= 1 to n do
  begin
   res[i,j]:= 0.0;
   for k:= 1 to n do   res[i,j]:= res[i,j]+m1[i,k]*m2[k,j];
  end
 end
end;


procedure emsubdiv(var m: mat1; var s: real; var res: mat1);

var i,j: integer;

begin
 for i:= 1 to n do
 begin
  for j:= 1 to n do
  begin
   if i=j then
    res[i,j]:= (1.0-m[i,j])/s
   else
    res[i,j]:= -m[i,j]/s;
  end
 end
end;


procedure vvadmul(var v1,v2: vec1; var s: real; var res: vec1);
```

```
var i: integer;

begin
 for i:= 1 to n do
  res[i]:=v1[i]+v2[i]*s;
end;


begin
 if yd1>0.0 then
 begin
  updflag:= pos;
  vtvmul(phi,te1d1,s1);
  e:= y-s1-a*yd1-b*ud1;
  mvmul(p1d1,phi,v1);
  vtvmul(phi,v1,s1);
  s1:= 1.0/(lam+s1);
  vsmul(v1,s1,kd1);
  vvadmul(te1d1,kd1,e,te1);
  vvtmul(kd1,phi,m1);
  emsubdiv(m1,lam,m2);
  mmmul(m2,p1d1,p1);
 end
 else
 begin
  updflag:= neg;
  vtvmul(phi,te2d1,s1);
  e:= y-s1-a*yd1-b*ud1;
  mvmul(p2d1,phi,v1);
  vtvmul(phi,v1,s1);
  s1:= 1.0/(lam+s1);
  vsmul(v1,s1,kd1);
  vvadmul(te2d1,kd1,e,te2);
  vvtmul(kd1,phi,m1);
  emsubdiv(m1,lam,m2);
  mmmul(m2,p2d1,p2);
 end
end;


procedure storeval;

begin
 it:= it+1;
 if (it-1) mod nout = 0 then
 begin
  actual:= (actual+1) mod maxpoint;
  stot[actual]:= (it-1)*sampint;
  stoy[actual]:= y*10.0;
  stor[actual]:= r*10.0;
  stou[actual]:= u*10.0;
  stoe[actual]:= e;
  stoati1[actual]:= te1[1];
  stobti1[actual]:= te1[2];
  stodel1[actual]:= te1[3];
  stoati2[actual]:= te2[1];
  stobti2[actual]:= te2[2];
  stodel2[actual]:= te2[3];
```

```
 end;
end;


procedure compsel;

begin
 case comp of
  none, fix:
  begin
   tec1d1:= tef1;
   tec2d1:= tef2;
  end;
  adptv:
  begin
   tec1d1:= te1;
   tec2d1:= te2;
  end;
 end
end;


procedure update;

begin
 phi[1]:= y; phi[2]:= u; phi[3]:= 1.0;
 uld1:=(u*t2+t1)/b;
 ud1:= u;          rbd1:= rb;
 yd1:= y;
 case updflag of
  pos:
  begin
   te1d1:= te1;
   p1d1:= p1;
   updflag:= nul;
  end;
  neg:
  begin
   te2d1:= te2;
   p2d1:= p2;
   updflag:= nul;
  end;
  nul:
 end;
end;

begin
 r:= adin(0); y:= adin(1);
 control;
 daout(0,u);
 estim:= (yd1<>0.0) and (sign(y) + sign(yd1) <> 0);
 if estim then rls;
 storeval;
 compsel;
 update;
end;


procedure setdefval;
```

```
begin
 reset(defval);
 readln(defval,ticks);
 readln(defval,outint);
 readln(defval,a,b);
 readln(defval,lam);
 readln(defval,am);
 readln(defval,a0);
 readln(defval,atilf1,btilf1,delf1);
 readln(defval,atilf2,btilf2,delf2);
 readln(defval,umax,umin);
 close(defval)
end;


procedure displaypar;
begin
 writeln;
 writeln('sampling intervall =        ',ticks*0.055:10:3);
 writeln('output intervall =          ',outint:10:3);
 writeln('a =                         ',a:10:3);
 writeln('b =                         ',b:10:3);
 writeln('forgetting factor lam =     ',lam:10:3);
 writeln('closed-loop parameter: am = ',am:10:3);
 writeln('observer polynomial: a0 =   ',a0:10:3);
 writeln('values of fixed compensation:');
 writeln(' atilf1 = ',atilf1:10:3,'   btilf1 = ',btilf1:10:3,'   delf1 = ',
         delf1:10:3);
 writeln(' atilf2 = ',atilf2:10:3,'   btilf2 = ',btilf2:10:3,'   delf2 = ',
         delf2:10:3);
 writeln('control signal limitations:');
 writeln(' umax =   ',umax:10:3,  '   umin =   ',umin:10:3);
 write('friction compensation: comp =   ');
 if comp  = none then writeln('none')
 else if comp = fix then writeln('fix')
 else writeln('adaptiv');
end;


procedure menu1;

var     answer: char;

begin
 repeat
  writeln;
  writeln('do you want to make any modifications?');
  writeln;
  write('answer [y/n]: ');
  readln(answer);
 until answer in ['y','Y','n','N'];
 if answer in ['y','Y'] then
 begin
  repeat
   writeln;
   writeln('choose one of the following possibilities:');
   writeln;
   writeln(' a: change sampling intervall');
```

```
    writeln(' b: change output intervall');
    writeln(' c: change model parameter a');
    writeln(' d: change model parameter b');
    writeln(' e: change forgetting factor');
    writeln(' f: change closed loop parameter am');
    writeln(' g: change observer polynominal');
    writeln(' h: change values of fixed compensation');
    writeln(' i: change control signal limitations');
    writeln(' j: change friction compensation mode');
    writeln;
    write('answer: ');
    readln(answer);
  until answer in ['a'..'j','A'..'J'];
  writeln;
  case answer of
   'a','A':
   begin
    writeln('sampling intervall = ticks * 0.055 sec = ',ticks*0.055:10:3);
    write('new value: ticks = ');
    readln(ticks);
   end;
   'b','B':
   begin
    writeln('ouput intervall = ',outint:10:3);
    write('new value: ');
    readln(outint);
   end;
   'c','C':
   begin
    writeln('a = ',a:10:3);
    write('new value: ');
    readln(a);
   end;
   'd','D':
   begin
    writeln('b = ',b:10:3);
    write('new value: ');
    readln(b);
   end;
   'e','E':
   begin
    writeln('lam = ',lam:10:3);
    write('new value: ');
    readln(lam);
   end;
   'f','F':
   begin
    writeln('am = ',am:10:3);
    write('new value: ');
    readln(am);
   end;
   'g','G':
   begin
    writeln('a0 = ',a0:10:3);
    write('new value: ');
    readln(a0);
   end;
   'h','H':
   begin
```

```
    writeln('atilf1 = ',atilf1:10:3,'   btilf1 = ',btilf1:10:3,'   delf1 =
            delf1:10:3);
    write('new values: ');
    readln(atilf1,btilf1,delf1);
    writeln('atilf2 = ',atilf2:10:3,'   btilf2 = ',btilf2:10:3,'   delf2 =
            delf2:10:3);
    write('new values: ');
    readln(atilf2,btilf2,delf2);
   end;
   'i','I':
   begin
    writeln('umax = ',umax:10:3,'   umin = ',umin:10:3);
    write('new values: ');
    readln(umax,umin);
   end;
   'j','J':
   begin
    write('comp = ');
    if comp = fix then writeln('fix') else writeln('adaptiv');
    repeat
     writeln('new mode:');
     writeln(' 1: without friction compensation');
     writeln(' 2: fixed compensation');
     writeln(' 3: adaptiv compensation');
     writeln;
     write('answer: ');
     readln(answer)
    until answer in ['1','2','3'];
    case answer of
     '1': comp:= none;
     '2': comp:= fix;
     '3': comp:= adptv;
    end;
   end;
  end;
 end
 else
 begin
  moddone:= true;
 end
end;


procedure menu2;

var     answer: char;

begin
 repeat
  writeln;
  writeln('choose one of the following possibilities:');
  writeln;
  writeln(' a: initialize another experiment');
  writeln(' b: initialize plots');
  writeln;
  write('answer: ');
  readln(answer);
 until answer in ['a'..'b','A'..'B'];
 if answer in ['b','B'] then startplt:= true;
```

```
end;


procedure menu3;

var     answer: char;

begin
 repeat
  writeln;
  writeln('choose one of the following possibilities:');
  writeln;
  writeln(' a: plot reference signal r');
  writeln(' b: plot signal y');
  writeln(' c: plot control signal u');
  writeln(' d: plot estimation error e');
  writeln(' e: plot estimated parameter atil1');
  writeln(' f: plot estimated parameter btil1');
  writeln(' g: plot estimated parameter del1');
  writeln(' h: plot estimated parameter atil2');
  writeln(' i: plot estimated parameter btil2');
  writeln(' j: plot estimated parameter del2');
  writeln(' k: display estimated parameters');
  writeln(' l: initialize another experiment');
  writeln(' m: stop the program');
  writeln;
  write('answer: ');
  readln(answer);
 until answer in ['a'..'m','A'..'M'];
 case answer of
  'a','A':
  begin
   plotarr:= stor;
   plotvar:= 'ref. signal r       ';
   plotgrf:= true;
  end;
  'b','B':
  begin
   plotarr:= stoy;
   plotvar:= 'output signal  y    ';
   plotgrf:= true;
  end;
  'c','C':
  begin
   plotarr:= stou;
   plotvar:= 'control signal  u   ';
   plotgrf:= true;
  end;
  'd','D':
  begin
   plotarr:= stoe;
   plotvar:= 'estimation error e  ';
   plotgrf:= true;
  end;
  'e','E':
  begin
   plotarr:= stoatil1;
   plotvar:= 'estim. par. atil1   ';
   plotgrf:= true;
```

```
   end;
   'f','F':
   begin
    plotarr:= stobtil1;
    plotvar:= 'estim. par. btil1   ';
    plotgrf:= true;
   end;
   'g','G':
   begin
    plotarr:= stodel1;
    plotvar:= 'estim. par. del1    ';
    plotgrf:= true;
   end;
   'h','H':
   begin
    plotarr:= stoatil2;
    plotvar:= 'estim. par. atil2   ';
    plotgrf:= true;
   end;
   'i','I':
   begin
    plotarr:= stobtil2;
    plotvar:= 'estim. par. btil2   ';
    plotgrf:= true;
   end;
   'j','J':
   begin
    plotarr:= stodel2;
    plotvar:= 'estim. par. del2    ';
    plotgrf:= true;
   end;
   'k','K':
   begin
    writeln;
    writeln('estimated parameters:');
    writeln;
    writeln(' atil1 = ',te1[1]:10:4,'   btil1 = ',te1[2]:10:4,'   del1 = ',
            te1[3]:10:4);
    writeln(' atil2 = ',te2[1]:10:4,'   btil2 = ',te2[2]:10:4,'   del2 = ',
            te2[3]:10:4);
   end;
   'l','L':
   begin
    stopplt:= true;
   end;
   'm','M':
   begin
    stopprog:= true;
   end;
  end;
end;


procedure paraminit;

var i,j: integer;

begin
 for i:= 1 to n do phi[i]:= 0.0;
```

```
 te1:= phi;      tec1d1:= phi;
 te2:= phi;      tec2d1:= phi;
 for i:= 1 to n do p1d1[i,i]:= 1000.0;
 p2d1:= p1d1;
 case comp of
  none:
  begin
   tef1[1]:= 0.0;  tef1[2]:= 0.0;   tef1[3]:= 0.0;
   tef2[1]:= 0.0;  tef2[2]:= 0.0;   tef2[3]:= 0.0;
  end;
  fix:
  begin
   tef1[1]:= atilf1;  tef1[2]:= btilf1;   tef1[3]:= delf1;
   tef2[1]:= atilf2;  tef2[2]:= btilf2;   tef2[3]:= delf2;
  end;
  adptv:
 end;
 s0:= -(a0+am)+(a+1.0);
 s1:= a0*am-a;
 r0:= b;
 pf:= 1.0-am;
 it:= 0;
 actual:= 0;
 sampint:= ticks*0.055;
 nout:= round(outint/0.055);
end;


procedure prepareplot;

var     i,j,expo10: integer;
        min,max,maxabs,pot10,ygmax,ygmin: real;

begin
 if (it-1) div nout < maxpoint then
 begin
  strtp:=1; maxpl:= actual;
 end
 else
 begin
  strtp:= (actual+1) mod maxpoint; maxpl:= maxpoint;
 end;
 min:= plotarr[1]; max:= plotarr[1];
 for i:= 2 to maxpl do
 begin
  j:= i mod maxpoint;
  if plotarr[j] > max then max:= plotarr[j];
  if plotarr[j] < min then min:= plotarr[j];
 end;
 if abs(max) > abs(min) then maxabs:= abs(max) else maxabs:= abs(min);
 if maxabs <> 0.0 then
 begin
  expo10:= trunc(ln(maxabs)/ln(10.0));
  if expo10 <= 0 then expo10:= expo10-1;
 end
 else
 begin
  expo10:= 0;
 end;
```

```
 pot10:= exp(expo10*ln(10.0));
 ygmax:= (trunc(maxabs/pot10)+1)*pot10;
 ygmin:= -ygmax;
 yscale:= ymax/(2.0*ygmax);
 tscale:= xmax/(stot[actual]-stot[strtp]);
 for i:= 1 to maxpl do
 begin
  graphx[i]:= round(tscale*(stot[(strtp+i-1) mod maxpoint]-stot[strtp]))+x0
  graphy[i]:= round(yscale*plotarr[(strtp+i-1) mod maxpoint])+y0;
 end;
 if not encode(lblx1,stot[strtp]:10:3) then writeln('error in encode 1');
 if not encode(lblx2,stot[(strtp+maxpl-1) mod maxpoint]:10:3) then
  writeln('error in encode 2');
 if not encode(lbly1,ygmax:10:3) then writeln('error in encode 3');
 if not encode(lbly2,ygmin:10:3) then writeln('error in encode 4');
end;


procedure plotgraph;

var     i: integer;

begin
 setdisplay(grafpg0,grafpg0,grafpg0);
 moveto(x0,y0-ymax div 2);
 line(xmax,0); line(0,ymax); line(-xmax,0); line(0,-ymax);
 moveto(x0,y0); line(xmax,0);
 fontgr(2);
 moveto(0,186); writegr('press key F1 to get control');
 moveto(0,171); writegr(lbly1);
 moveto(0,35); writegr(lbly2);
 moveto(60,20); writegr(lblx1);
 moveto(500,20); writegr(lblx2);
 moveto(0,0); writegr('plotted varialble: '); writegr(plotvar);
 moveto(graphx[1],graphy[1]);
 for i:= 2 to maxpl do
 begin
  lineto(graphx[i],graphy[i]);
 end;
 eventqueue(true);
 stopgraf:= false;
 repeat
  if keyevent(false,evnt) then
  begin
   if evnt.scancode = 59 then stopgraf:= true;
  end
 until stopgraf;
 stopevent;
 setdisplay(0,0,0);
end;


begin
 initadda;
 daout(0,0.0);
 daout(1,0.0);
 initgrafix(ibmhires);
 setdefval;
 stopprog:= false;
```

```
 repeat
  startplt:= false;
  repeat
   moddone:= false;
   repeat
    displaypar;
    menu1;
   until moddone;
   paraminit;
   writeln;
   writeln('strike key F1 to start the controller');
   eventqueue(true);
   startctrl:= false;
   repeat
    if keyevent(false,evnt) then
    begin
     if evnt.scancode = 59 then startctrl:= true;
    end
   until startctrl;
   writeln;
   writeln('     controller is running');
   writeln('strike key F1 to stop the controller');
   writeln;
   stopctrl:= false;
   schedule(foregnd1,ticks);
   repeat
    if keyevent(false,evnt) then
    begin
     if evnt.scancode = 59 then stopctrl:= true;
    end
   until stopctrl;
   endsched;
   stopevent;
   daout(0,0.0);
   menu2;
  until startplt;
  stopplt:= false;
  repeat
   menu3;
   if plotgrf then
   begin
    prepareplot;
    plotgraph;
    plotgrf:= false;
   end;
  until stopplt or stopprog
 until stopprog;
end.
```

```
1                   ; ticks
0.055               ; ouint
0.9   0.13          ; a, b
0.99                ; lam
0.75                ; am
0.8                 ; a0
0.00 0.0 -0.01      ; tef1
0.00 0.0  0.01      ; tef2
1.0 -1.0            ; umax, umin
```

```
sampling intervall =                    0.055
output intervall =                      0.055
a =                                     0.900
b =                                     0.130
forgetting factor lam =                 0.990
closed-loop parameter: am =             0.900
observer polynomial: a0 =               0.500
values of fixed compensation:
 atilf1 =      0.000   btilf1 =       0.000   delf1 =      -0.010
 atilf2 =      0.000   btilf2 =       0.000   delf2 =       0.010
control signal limitations:
 umax =        1.000   umin =         -1.000
friction compensation: comp =   fix

do you want to make any modifications?

answer [y/n]: y



choose one of the following possibilities:

 a: change sampling intervall
 b: change output intervall
 c: change model parameter a
 d: change model parameter b
 e: change forgetting factor
 f: change closed loop parameter am
 g: change observer polynominal
 h: change values of fixed compensation
 i: change control signal limitations
 j: change friction compensation mode

answer: c

a =       0.900
new value: 0.8
```

```
 a: initialize another experiment
 b: initialize plots

answer: b

choose one of the following possibilities:

 a: plot reference signal r
 b: plot signal y
 c: plot control signal u
 d: plot estimation error e
 e: plot estimated parameter atil1
 f: plot estimated parameter btil1
 g: plot estimated parameter del1
 h: plot estimated parameter atil2
 i: plot estimated parameter btil2
 j: plot estimated parameter del2
 k: display estimated parameters
 l: initialize another experiment
 m: stop the program

answer: c
```

```
{-----------------------------------------------------------------------

PROGLOG - IDENT
---------------

PURPOSE:

   This program is to make an open-loop identification of a DC motor
   sytem.


USAGE:

   The input signal from a signal generator is connected to
   the analog input channel 0 and the output of the process to
   the analog input channel 1. The analog output channel 1 is the
   input signal to the system to identify and should be connected
   to the process.
   After typing the name of the executable file the name of the
   file with the default values should be specified. This file
   must have the following form:

     1           ; ticks  (number of ticks between two calls of foregr.
     0.5         ; ouint  (output interval for plots)
     0.0 0.0     ; a, b   (initial values for model parameters)
     0.99        ; lam    (forgetting factor)

   The rest of the program is self-explicable.


DATE:

   May 28 1985


AUTHOR

   Konrad Braun

-----------------------------------------------------------------------}

{$include: 'addab.int'}

program test4(input,output,defval);


uses addab(adin,daout,initadda);


const   n=3;
        x0= 99;     y0= 110;     xmax= 500;  ymax=150;
        maxpoint= 200;

type    vec1=   array [1..n] of real;

        mat1=   array [1..n,1..n] of real;

{$include: 'grconst.inc'}
```

```
var     defval: text;

        i,j,ticks,actual,strtp,maxpl,it,nout          : integer;

        a,b,y,yd1,u,ud1,e,lam,
        t,sampint,tscale,yscale,outint,               : real;

        phi,te1,te1d1,te2,te2d1,tef1,tef2,
        tec1d1,tec2d1                                 : vec1;

        p1,p1d1,p2,p2d1                               : mat1;

        stopprog,stopplt,startplt,moddone,
        startctrl,stopctrl,stopgraf,plotgrf           : boolean;

        updflag                                       : (pos, neg, nul);

        graphx,graphy                : array[1..maxpoint] of integer;

        stot,stoy,stou,stoe,
        stoatil1,stobtil1,stodel1,
        stoatil2,stobtil2,stodel2,
        plotarr                      : array[0..maxpoint-1] of real;

        plotvar                                       : string(20);

        lblx1,lblx2,lbly1,lbly2                       : lstring(9);

        evnt                                          : event;

value   updflag:= nul;

{$include: 'grextrn.inc'}


procedure schedule(procedure fg [public]; ticks: integer); extern;


procedure endsched; extern;


function sign(x: real): integer;

begin
 sign:= ord(x>0.0)-ord(x<0.0)
end;


procedure foregnd1 [public];

var     d1,t1,t2: real;

        estim: boolean;


procedure rls;

var   s1: real;
      kd1,v1: vec1;
```

```
      m1,m2: mat1;


procedure vsmul(var v: vec1; var s: real; var res: vec1);

var i: integer;

begin
 for i:= 1 to n do res[i]:= v[i]*s;
end;


procedure vvtmul(var v1,v2: vec1; var res: mat1);

var i,j: integer;

begin
 for i:= 1 to n do
  for j:= 1 to n do  res[i,j]:= v1[i]*v2[j];
end;


procedure vtvmul(var v1,v2: vec1; var res: real);

var i: integer;

begin
 res:= 0.0;
 for i:= 1 to n do  res:= res+v1[i]*v2[i];
end;


procedure mvmul(var m: mat1; var v,res: vec1);

var i,j: integer;

begin
 for i:= 1 to n do
 begin
  res[i]:= 0.0;
  for j:= 1 to n do  res[i]:= res[i]+m[i,j]*v[j];
 end
end;


procedure mmmul(var m1,m2,res: mat1);

var i,j,k: integer;

begin
 for i:= 1 to n do
 begin
  for j:= 1 to n do
  begin
   res[i,j]:= 0.0;
   for k:= 1 to n do   res[i,j]:= res[i,j]+m1[i,k]*m2[k,j];
  end
 end
end;
```

```
procedure emsubdiv(var m: mat1; var s: real; var res: mat1);

var i,j: integer;

begin
 for i:= 1 to n do
 begin
  for j:= 1 to n do
  begin
   if i=j then
    res[i,j]:= (1.0-m[i,j])/s
   else
    res[i,j]:= -m[i,j]/s;
  end
 end
end;


procedure vvadmul(var v1,v2: vec1; var s: real; var res: vec1);

var i: integer;

begin
 for i:= 1 to n do
  res[i]:=v1[i]+v2[i]*s;
end;


begin
 if yd1>0.0 then
 begin
  updflag:= pos;
  vtvmul(phi,te1d1,s1);
  e:= y-s1-a*yd1-b*ud1;
  mvmul(p1d1,phi,v1);
  vtvmul(phi,v1,s1);
  s1:= 1.0/(lam+s1);
  vsmul(v1,s1,kd1);
  vvadmul(te1d1,kd1,e,te1);
  vvtmul(kd1,phi,m1);
  emsubdiv(m1,lam,m2);
  mmmul(m2,p1d1,p1);
 end
 else
 begin
  updflag:= neg;
  vtvmul(phi,te2d1,s1);
  e:= y-s1-a*yd1-b*ud1;
  mvmul(p2d1,phi,v1);
  vtvmul(phi,v1,s1);
  s1:= 1.0/(lam+s1);
  vsmul(v1,s1,kd1);
  vvadmul(te2d1,kd1,e,te2);
  vvtmul(kd1,phi,m1);
  emsubdiv(m1,lam,m2);
  mmmul(m2,p2d1,p2);
 end
```

```
end;


procedure storeval;

begin
 it:= it+1;
 if (it-1) mod nout = 0 then
 begin
  actual:= (actual+1) mod maxpoint;
  stot[actual]:= (it-1)*sampint;
  stoy[actual]:= y*10.0;
  stou[actual]:= u*10.0;
  stoe[actual]:= e;
  stoatil1[actual]:= te1[1];
  stobtil1[actual]:= te1[2];
  stodel1[actual]:= te1[3];
  stoatil2[actual]:= te2[1];
  stobtil2[actual]:= te2[2];
  stodel2[actual]:= te2[3];
 end;
end;


procedure update;

begin
 phi[1]:= y; phi[2]:= u; phi[3]:= 1.0;
 ud1:= u;
 yd1:= y;
 case updflag of
  pos:
  begin
   te1d1:= te1;
   p1d1:= p1;
   updflag:= nul;
  end;
  neg:
  begin
   te2d1:= te2;
   p2d1:= p2;
   updflag:= nul;
  end;
  nul:
 end;
end;

begin
 u:= adin(0); y:= adin(1);
 daout(0,u);
 estim:= (yd1<>0.0) and (sign(y) + sign(yd1) <> 0);
 if estim then rls;
 storeval;
 update;
end;


procedure setdefval;
```

```
begin
 reset(defval);
 readln(defval,ticks);
 readln(defval,outint);
 readln(defval,a,b);
 readln(defval,lam);
 close(defval)
end;


procedure displaypar;
begin
 writeln;
 writeln('sampling intervall =        ',ticks*0.055:10:3);
 writeln('output intervall =          ',outint:10:3);
 writeln('a =                         ',a:10:3);
 writeln('b =                         ',b:10:3);
 writeln('forgetting factor lam =     ',lam:10:3);
end;


procedure menu1;

var     answer: char;

begin
 repeat
  writeln;
  writeln('do you want to make any modifications?');
  writeln;
  write('answer [y/n]: ');
  readln(answer);
 until answer in ['y','Y','n','N'];
 if answer in ['y','Y'] then
 begin
  repeat
   writeln;
   writeln('choose one of the following possibilities:');
   writeln;
   writeln(' a: change sampling intervall');
   writeln(' b: change output intervall');
   writeln(' c: change model parameter a');
   writeln(' d: change model parameter b');
   writeln(' e: change forgetting factor');
   writeln;
   write('answer: ');
   readln(answer);
  until answer in ['a'..'e','A'..'E'];
  writeln;
  case answer of
   'a','A':
   begin
    writeln('sampling intervall = ticks * 0.055 sec = ',ticks*0.055:10:3);
    write('new value: ticks = ');
    readln(ticks);
   end;
   'b','B':
   begin
    writeln('ouput intervall = ',outint:10:3);
```

```
    write('new value: ');
    readln(outint);
   end;
   'c','C':
   begin
    writeln('a = ',a:10:3);
    write('new value: ');
    readln(a);
   end;
   'd','D':
   begin
    writeln('b = ',b:10:3);
    write('new value: ');
    readln(b);
   end;
   'e','E':
   begin
    writeln('lam = ',lam:10:3);
    write('new value: ');
    readln(lam);
   end;
  end;
 end
 else
 begin
  moddone:= true;
 end
end;


procedure menu2;

var     answer: char;

begin
 repeat
  writeln;
  writeln('choose one of the following possibilities:');
  writeln;
  writeln(' a: initialize another identification');
  writeln(' b: initialize plots');
  writeln;
  write('answer: ');
  readln(answer);
 until answer in ['a'..'b','A'..'B'];
 if answer in ['b','B'] then startplt:= true;
end;


procedure menu3;

var     answer: char;

begin
 repeat
  writeln;
  writeln('choose one of the following possibilities:');
  writeln;
  writeln(' a: plot control signal u');
```

```
  writeln(' b: plot signal y');
  writeln(' c: plot estimation error e');
  writeln(' d: plot estimated parameter atil1');
  writeln(' e: plot estimated parameter btil1');
  writeln(' f: plot estimated parameter del1');
  writeln(' g: plot estimated parameter atil2');
  writeln(' h: plot estimated parameter btil2');
  writeln(' i: plot estimated parameter del2');
  writeln(' j: display estimated parameters');
  writeln(' k: initialize another experiment');
  writeln(' l: stop the program');
  writeln;
  write('answer: ');
  readln(answer);
 until answer in ['a'..'l','A'..'L'];
 case answer of
  'a','A':
  begin
   plotarr:= stou;
   plotvar:= 'control signal  u   ';
   plotgrf:= true;
  end;
  'b','B':
  begin
   plotarr:= stoy;
   plotvar:= 'output signal  y    ';
   plotgrf:= true;
  end;
  'c','C':
  begin
   plotarr:= stoe;
   plotvar:= 'estimation error e  ';
   plotgrf:= true;
  end;
  'd','D':
  begin
   plotarr:= stoatil1;
   plotvar:= 'estim. par. atil1   ';
   plotgrf:= true;
  end;
  'e','E':
  begin
   plotarr:= stobtil1;
   plotvar:= 'estim. par. btil1   ';
   plotgrf:= true;
  end;
  'f','F':
  begin
   plotarr:= stodel1;
   plotvar:= 'estim. par. del1    ';
   plotgrf:= true;
  end;
  'g','G':
  begin
   plotarr:= stoatil2;
   plotvar:= 'estim. par. atil2   ';
   plotgrf:= true;
  end;
  'h','H':
```

```
  begin
   plotarr:= stobtil2;
   plotvar:= 'estim. par. btil2   ';
   plotgrf:= true;
  end;
  'i','I':
  begin
   plotarr:= stodel2;
   plotvar:= 'estim. par. del2    ';
   plotgrf:= true;
  end;
  'j','J':
  begin
   writeln;
   writeln('estimated parameters:');
   writeln;
   writeln(' atil1 = ',te1[1]:10:4,'   btil1 = ',te1[2]:10:4,'   del1 = ',
           te1[3]:10:4);
   writeln(' atil2 = ',te2[1]:10:4,'   btil2 = ',te2[2]:10:4,'   del2 = ',
           te2[3]:10:4);
  end;
  'k','K':
  begin
   stopplt:= true;
  end;
  'l','L':
  begin
   stopprog:= true;
  end;
 end;
end;


procedure paraminit;

var i,j: integer;

begin
 for i:= 1 to n do phi[i]:= 0.0;
 te1:= phi;      tec1d1:= phi;
 te2:= phi;      tec2d1:= phi;
 for i:= 1 to n do p1d1[i,i]:= 1000.0;
 p2d1:= p1d1;
 it:= 0;
 actual:= 0;
 sampint:= ticks*0.055;
 nout:= round(outint/0.055);
end;


procedure prepareplot;

var     i,j,expo10: integer;
        min,max,maxabs,pot10,ygmax,ygmin: real;

begin
 if (it-1) div nout < maxpoint then
 begin
  strtp:=1; maxpl:= actual;
```

```
 end
 else
 begin
  strtp:= (actual+1) mod maxpoint; maxpl:= maxpoint;
 end;
 min:= plotarr[1]; max:= plotarr[1];
 for i:= 2 to maxpl do
 begin
  j:= i mod maxpoint;
  if plotarr[j] > max then max:= plotarr[j];
  if plotarr[j] < min then min:= plotarr[j];
 end;
 if abs(max) > abs(min) then maxabs:= abs(max) else maxabs:= abs(min);
 if maxabs <> 0.0 then
 begin
  expo10:= trunc(ln(maxabs)/ln(10.0));
  if expo10 <= 0 then expo10:= expo10-1;
 end
 else
 begin
  expo10:= 0;
 end;
 pot10:= exp(expo10*ln(10.0));
 ygmax:= (trunc(maxabs/pot10)+1)*pot10;
 ygmin:= -ygmax;
 yscale:= ymax/(2.0*ygmax);
 tscale:= xmax/(stot[actual]-stot[strtp]);
 for i:= 1 to maxpl do
 begin
  graphx[i]:= round(tscale*(stot[(strtp+i-1) mod maxpoint]-stot[strtp]))+x0;
  graphy[i]:= round(yscale*plotarr[(strtp+i-1) mod maxpoint])+y0;
 end;
 if not encode(lblx1,stot[strtp]:10:3) then writeln('error in encode 1');
 if not encode(lblx2,stot[(strtp+maxpl-1) mod maxpoint]:10:3) then
  writeln('error in encode 2');
 if not encode(lbly1,ygmax:10:3) then writeln('error in encode 3');
 if not encode(lbly2,ygmin:10:3) then writeln('error in encode 4');
end;


procedure plotgraph;

var     i: integer;

begin
 setdisplay(grafpg0,grafpg0,grafpg0);
 moveto(x0,y0-ymax div 2);
 line(xmax,0); line(0,ymax); line(-xmax,0); line(0,-ymax);
 moveto(x0,y0); line(xmax,0);
 fontgr(2);
 moveto(0,186); writegr('press key F1 to get control');
 moveto(0,171); writegr(lbly1);
 moveto(0,35); writegr(lbly2);
 moveto(60,20); writegr(lblx1);
 moveto(500,20); writegr(lblx2);
 moveto(0,0); writegr('plotted varialble: '); writegr(plotvar);
 moveto(graphx[1],graphy[1]);
 for i:= 2 to maxpl do
 begin
```

```
   lineto(graphx[i],graphy[i]);
  end;
  eventqueue(true);
  stopgraf:= false;
  repeat
   if keyevent(false,evnt) then
   begin
    if evnt.scancode = 59 then stopgraf:= true;
   end
  until stopgraf;
  stopevent;
  setdisplay(0,0,0);
end;


begin
 initadda;
 daout(0,0.0);
 daout(1,0.0);
 initgrafix(ibmhires);
 setdefval;
 stopprog:= false;
 repeat
  startplt:= false;
  repeat
   moddone:= false;
   repeat
    displaypar;
    menu1;
   until moddone;
   paraminit;
   writeln;
   writeln('strike key F1 to start the identification');
   eventqueue(true);
   startctrl:= false;
   repeat
    if keyevent(false,evnt) then
    begin
     if evnt.scancode = 59 then startctrl:= true;
    end
   until startctrl;
   writeln;
   writeln('     identification is running');
   writeln('strike key F1 to stop the identification');
   writeln;
   stopctrl:= false;
   schedule(foregnd1,ticks);
   repeat
    if keyevent(false,evnt) then
    begin
     if evnt.scancode = 59 then stopctrl:= true;
    end
   until stopctrl;
   endsched;
   stopevent;
   daout(0,0.0);
   menu2;
  until startplt;
  stopplt:= false;
```

```
  repeat
   menu3;
   if plotgrf then
   begin
    prepareplot;
    plotgraph;
    plotgrf:= false;
   end;
  until stopplt or stopprog
 until stopprog;
end.
```