ON THE SAMPLING PERIOD IN STANDARD AND FUZZY CONTROL ALGORITHMS FOR SERVODRIVES

A Multicriterial Design and a Timing Strategy for Constant Sampling

Dan Mihai

University of Craiova, Decebal Blvd, 107, Craiova, Romania

Keywords: Sampling period, PI algorithm, Fuzzy control, On-line timing, Servodrives.

Abstract: The paper deals with the best choice for the control sampling period in term of a multicriterial conditioning, with the on-line timing and with a comparison between the conventional (like PI) control algorithms and the fuzzy control. Several useful relations are followed by diagrams obtained in simulation and by different real-time recordings both for the timing and for characteristic variables of the system. Implementations with microcontroller and DSP are used for analyzing the design criterion and the timing strategy. The application field concerns a servodrive, so the real-time constraints are quite strong. The author conceived a general control strategy for the on-line timing based on imbricate interrupts, each pulse encoder acting on the hardware input interrupt of the control processor.

1 INTRODUCTION

The sampling frequency plays an essential role in implementing a digital control algorithm in real-time, especially for the fast systems. Most of the reference books give evaluations only for the upper limit of the sampling period (T), as if the ideal value would be as little as possible – only the capacity of the control processor being the constraint. The efficient choice of the sampling rate in closed-loop system is based on its influence on the performance of the control system. The absolute lower bound to the sample rate is set by the system bandwidth. The classical controllers (and their loops) are not robust and their tuning (including the additional T parameter) - although stated as well settled (Astrom, 1997), seems to be very difficult in complex conditions. Not a few applications and studies concern the sampling period design for different kind of fuzzy control. An earlier idea (Coleman, 1994) about the robustness comparison between fuzzy logic, PID control and sliding mode control, will be extended now in the area of the control sampling period.

During the last decades, the electrical drives field has integrated more and more design techniques, fast control processors and acquisition modules for high performance platforms. A hybrid approach is to have an inner current loop monitored by a fuzzy controller (Mrozek, 2000) while the main speed loop is monitored by a classical PI controller. Another approach is to design a self tuning fuzzy logic controller, based on some desired output behaviour and hence, does not requiring a precise model of the machine (Ibbini, 2002). Sometimes, the results are quite close in term of performance (in steady state or dynamic regime) but the implementation effort is much lower for the fuzzy solution (Silveira, 2002). Industrial equipment support from few kHz to 20 kHz sample rate for the velocity loop. This high rate of sampling combined with the velocity observer, allows equipment to provide a very fast control for industrial servo drives. Despite the availability of several high performance DSP controllers, many researchers are interested in designing optimal control algorithms based on low-cost solutions; such approach is typical for linear and sliding-mode controllers designed for a DC servo drive with a microcontroller and low sampling rate, typical for embedded systems (Kosek, 2007).

The author developed a general on-line timing for all digital control algorithms for the servodrives with a hardware position loop and a software one for the speed, proposing several relations for the multicriterial correlation of the involved parameters, T included. Several such relations require the T value to be superior to some threshold limits.

Mihai D. (2008).
ON THE SAMPLING PERIOD IN STANDARD AND FUZZY CONTROL ALGORITHMS FOR SERVODRIVES - A Multicriterial Design and a Timing Strategy for Constant Sampling.
In *Proceedings of the Fifth International Conference on Informatics in Control, Automation and Robotics - SPSMC*, pages 72-77
DOI: 10.5220/0001477600720077

2 THE SERVODRIVE AND THE ON-LINE CONTROL TIMING

Figure 1a presents the main parts of the system. Each encoder pulse acts on the interrupt entry of the processor. The next control strategy and the timing remain the same for any motor (and its associated power supply), for different kind of control algorithms (standard, fuzzy). The general systemic structure is given by figure 1b; figure 1c is for a conventional control and the next one (1d) presents the fuzzy control. The main notations: N_α*,$N_{\alpha k}$ - position set-point and the real position, in encoder pulses; $\varepsilon_{\alpha k}$, $\Delta\varepsilon_{\alpha k}$: position error, its variation referred to a sampling period; $\Delta N_{\alpha k}$ - pulses encoder during T; c_k, c_{kout} - the computed control and its outputted value; $Norm_i$: normalization blocks for each Fuzzy Logic Controller (FLC); CPB: Control Processing Block; PS - Power supply with digital control input; T_{gen} - torque generator; M - motor; En - encoder. The encode has $N_{p/r}$ pulses per revolution and the speed is monitored through a software image:

$$\omega_{ks} \approx \frac{\alpha_k - \alpha_{k-1}}{T} = \frac{2\pi \cdot k_{div} \cdot \Delta N_k}{N_{p/r} \cdot T} = c_{sp} \cdot \Delta N_k \qquad (1)$$

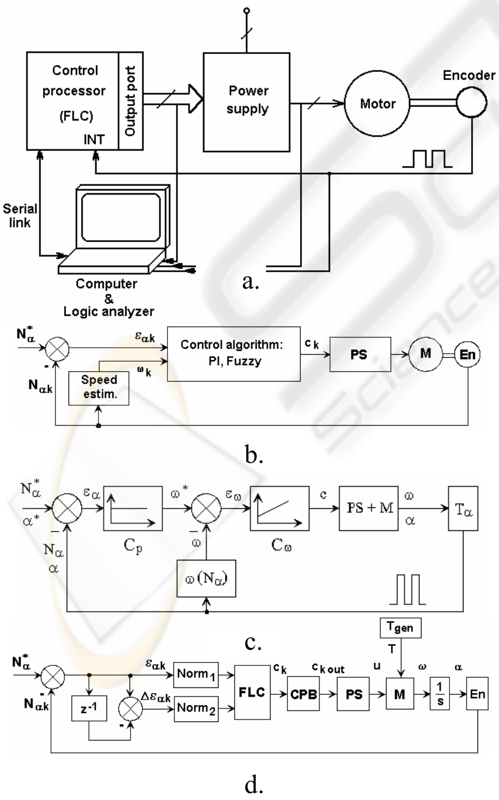


Figure 1: The drive with different controllers.

k_{div} is a division / multiplication factor for encoder pulses. The real-time control strategy is based on 2 imbricate interrupts – figure 2. INT0 is a high level priority interrupt generated by encoder pulses (the falling edge). The low level priority interrupt is software generated, marking the sampling period - T. PULSE means the encoder signals. For standard or non-conventional control algorithms, T must be correlated with: a. the specific system dynamic; b. n_{min} - the minimum accepted value of the real speed for which $\omega_{k\ soft}$ is detectable; c. n_{lw} - the size of the data word (register) for ω_{ks}; d. the accepted resolution for the speed; e. the program length of the on-line processing; f. The amount of memory available for on-line recordings. **b., c** and d**.** give the next restrictions for T:

$$\frac{60 \cdot k_{div}}{N_{p/r} \cdot n_{min}\ [RPM]} \le T \le \frac{(2^{n_{lw}} - 1) \cdot 60 \cdot k_{div}}{N_{p/r} \cdot n_{max}\ [RPM]} \qquad (2)$$

When the range speed covers a full data register, for having 1 LSB at minimum speed, T must be:

$$T \ge \frac{(2^{n_{reg}} - 1) \times 60 \times k_{div}}{N_{p/r} \times n_{max}[RPM]} \qquad (3)$$

The e. condition generates another constraint for T (Mihai, 1999). INT0 requested by the falling edge encoder pulses computes $\varepsilon_{\alpha k}$, ΔN_k and needs the time-Δt_{INT0}. $\Delta t_{av.instr.}$ is the average time for a processor instruction. Having the code program length for the software interrupt routine-$N_{max.ALG.\ instr.}$ imposed by the algorithm, T must be:

$$T \ge \frac{N_{max\ ALG\ instr.} \cdot \Delta t_{av.\ instr.}}{1 - \dfrac{n_{max} \cdot N_{p/r} \cdot \Delta t_{INT0}}{60 \cdot k_{div}}} \qquad (4)$$

As for f. condition, the data memory space for all on-line records is given by the number of data bytes

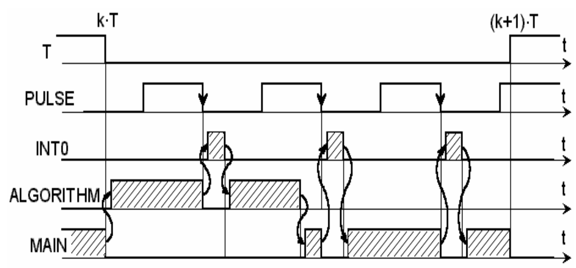


Figure 2: The proposed timing for on-line control based on interupts.

n_{Bytes} saved for each T and the regime duration Δt_{pos}. A too much little T can lead to an outrunning of the available memory space $V_{data\ mem.}$. Then:

$$T \geq \frac{\Delta t_{pos.\max} \cdot n_{Bytes}}{V_{data\ mem.}} \quad (5)$$

The basic software structure for the on-line control is presented in figure 3. The main program performs an initial preparation of the interrupt system and T2 timer. Then, the interruptible loop makes some auxiliary processing concerning data displaying and a test for the flag F which signals a null position error. Main tasks are those monitored by the hardware interrupt INT0 and the software interrupt ALG / T2. The first is a very fast one and is absolutely the same for all type algorithms, which control the position and speed. A more complex interrupt routine is ALG / T2. The specific tasks concern some additional computing procedures for the control c_k and a characteristic up-to-date for addresses content allocated to regressive variables of standard algorithms. The processing of the obtained control means the extraction of one effective control $c_{k\ out}$ in 8 bit format which acts on a power supply.

2.1 Standard Digital (Micro) Controller

The author combined the computations for both loops into a single relation for the control:

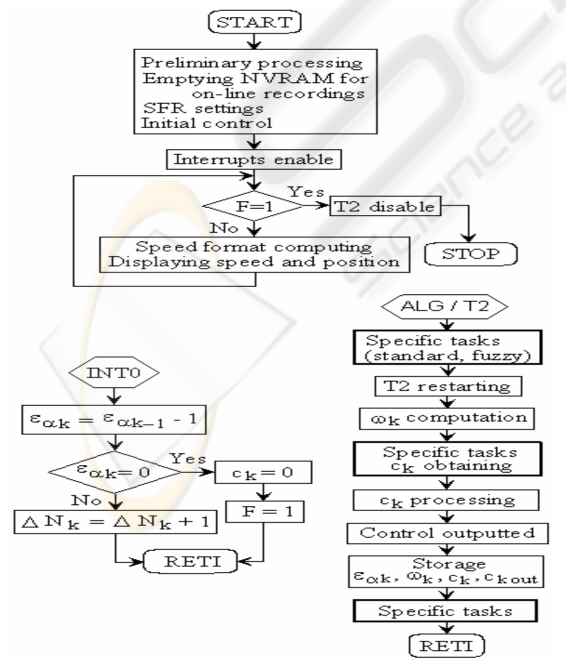


Figure 3: Flow chart of the on-line control program.

$$c_k = c_{k-1} + k_{p\omega} \cdot \left(\varepsilon_{\omega k} - \varepsilon_{\omega k-1}\right) + k_{p\omega} \cdot T \cdot \varepsilon_{\omega k} / T_i \quad (6)$$

$k_{p\alpha}$, $k_{p\omega}$ and T_i are the tuning parameters of position and speed loops. Figure 4 has a more detailed systemic structure of the figure 2a. The next form was obtained as an on-line optimal one:

$$c_k = c_{k-1} + A \cdot \Delta N_{k-1} + B \cdot \Delta Nk + C \cdot \varepsilon_{\alpha k} \quad (7)$$

$$A = k_{p\omega} \cdot c_{sp};\ B = -k_{p\omega} \cdot c_{sp} \cdot \left(k_{p\alpha} + T / T_i\right) \qquad C = -k_{p\omega} \cdot k_{p\alpha} \cdot T / T_i \quad (8)$$

A, B and C are the new tuning parameters and all other variables are delivered by INT0. The real-time implementation was prepared by various simulations on a model having the structure and the characteristics very close to the real operation and capabilities of the system and of the microcontroller. The algorithm was applied for simulation and on-line control for a drive system with: a 12 V DC brushed low-inertia motor; an 8 bits microcontroller; an encoder with 2500 lines / rev. A multicriterial optimal conditioning (Mihai, 1999, 2004) of the involved data meant T = 2.456 ms and c_{sp} = 1.02 ≅1 (an ideal value). The figure 5 presents the simulation results by the main macroscopic variables. The on-line results are those from figure 6, the behaviour being like the expected one by simulation. Some differences are in connection with a particular strategy for the pre-final time segment (Mihai, 2004). Figure 7 is a witness of what is happening in real-time, the analyser recordings giving details for the timing (including the T value, interrupt events) and for precise evaluations for each activated task. Notations: SPER-sampling period; PULSE- encoder pulses; INT0-external interrupt service routine; PROC-all speed loop tasks; ARITH- arithmetic routines; SCON-control tasks. Figure 7a reveals the timing for a low speed and the total processing time for having a control: 452 μs. The next diagram is for the rated speed and the real T - 2.47 ms. 7c makes a precise evaluation of the final position error: 2.5 pulses, that meaning 1 / 1000 rev. during 11.37 ms.

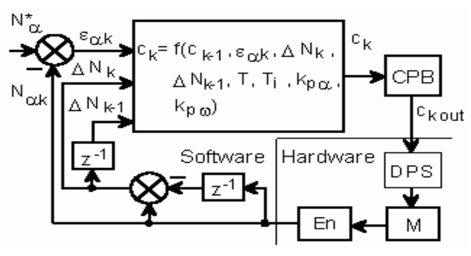


Figure 4: For the standard control algorithm.

Fig. 8 is for T= 2.456 ms (the ideal value) and T = 1ms. It can be seen the worsening of the performance; the control is saturated and a big position overshoot is present. So, a lower T value does not bring a higher performance.

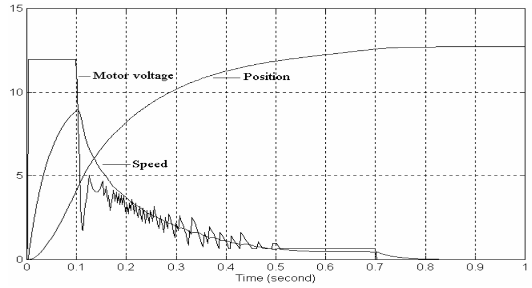


Figure 5: Simulation results / standard algorithm.

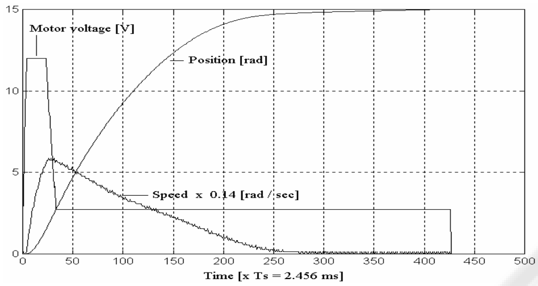
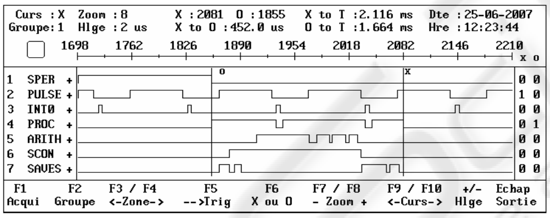
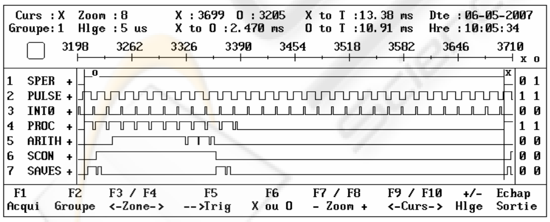


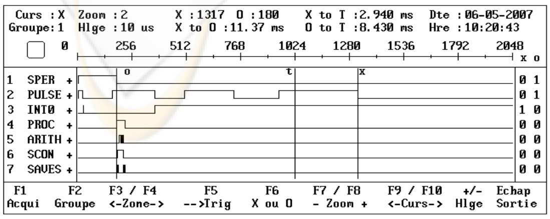
Figure 6: Real-time results / standard algorithm.



a



b



c

Figure 7: The on-line tasks / standard algorithm.

2.2 Standard Algorithm by DSP Controller

The first idea for improving the bad results from fig. 8b is to use a much more performing hardware. The next experiment was made with a brushless DC motor and a DSP controller (Technosoft, 1997). The figure 9a presents the system. The results (in real-time) from figure 9b are for no-load conditions. The figure 9c proves a good general tuning when the motor has a load. This first two result sets were for T=1 ms (speed loop) and T=0.1 ms (current loop). With a faster control sampling (twice), the results are loosing the quality-fig. 9d. A good choice for T is better than an expensive hardware solution.

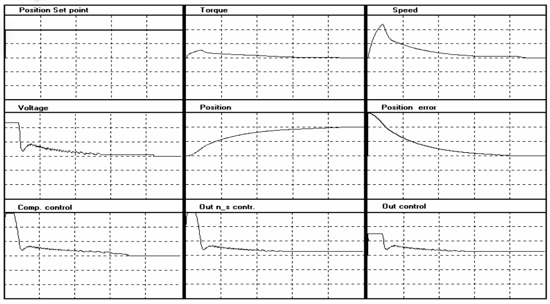
2.3 A Fuzzy Digital Controller

The input variables for the FLC are:

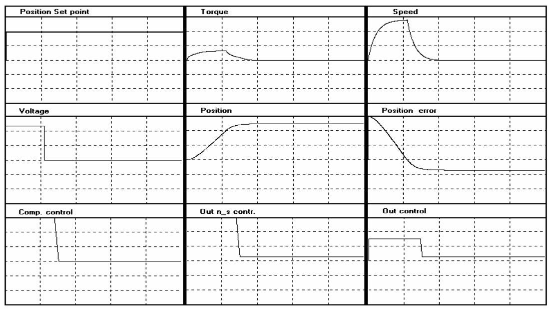
$$\varepsilon_{\alpha nk} = (N_\alpha^* - N_{\alpha k}) \cdot \varepsilon_{\alpha nk\ max} / N_\alpha^* \geq 0 \qquad (9)$$

$$\Delta\varepsilon_{\alpha nk} = \varepsilon_{\alpha n\ k} - \varepsilon_{\alpha\ nk-1} = \Delta Nk \cdot \Delta\varepsilon_{\alpha nk\ max} \cdot c_{sp} / \Omega_{max} \leq 0 \qquad (10)$$

The most reduced on-line computational effort is obtained using a look-up table (LUT) filled off-line. Fig. 10 gives the image of the equivalent systemic structure of FLC. The control values are stored by the columns concatenation of a matrix with the final control values, so the additional software block CPB is no more necessary. The fuzzy LUT strategy was



a



b

Figure 8: T = 2.456 ms (a) and T = 1 ms (b).

applied for the same servodrive as for 2.1. The main characteristic elements are presented by fig. 11. The notations: **az-**almost zero; **vs**-very small; **s**-small; **rs**-relative small; **m-**medium; **b**-big; **vb**-very big. The off-line tuning for the fuzzy rule base was made by

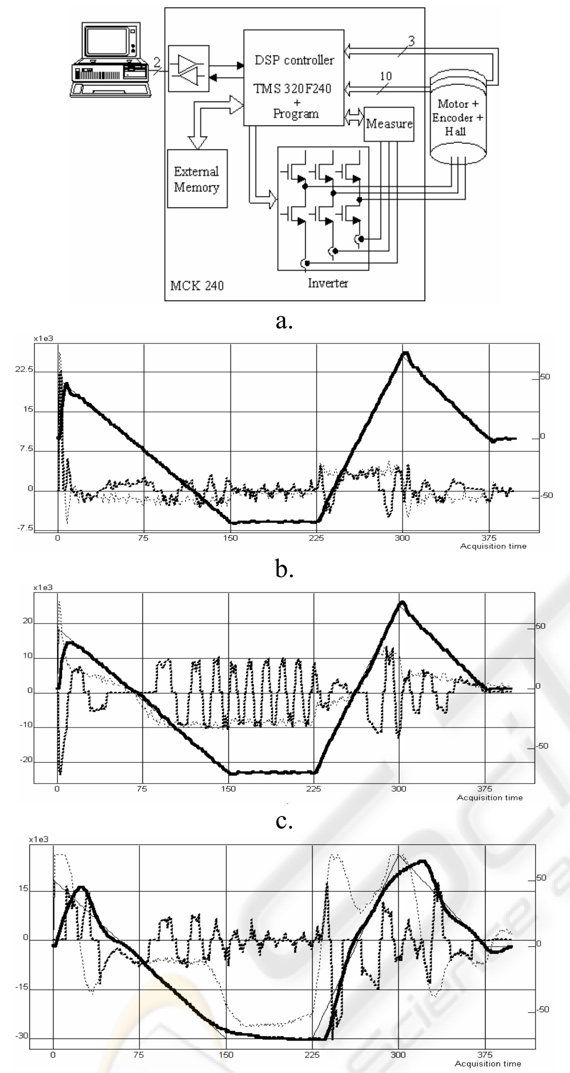


Figure 9: The real-time results for a standard algoritm and a DSP controller.

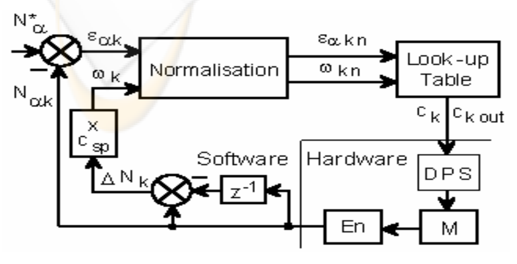


Figure 10: A LUT based FLC.

simulation on model, with the results from the figure 12. The on-line results are depicted in figure 13 and the on-line timing is given by the figure 14. It can be notice a good concordance between the simulated and the real-time results. The meaning of the additional notations used by the figure 14: NORM-normalization task; LUT-searching in look-up table. The apparent discrepancy between the position smooth evolution and the speed diagram is explained by the fact that the software image ΔN_k is a truncated value for speed, while the real speed and the position support a filtering effect of mechanical inertia. The ringing of the control is, basically, a result of fuzzy rules commutation. The control variable evolution (motor voltage) reveals a very sensitive behaviour of the controller, better than for the standard controller–the figures 5 and 6. The quality of the whole evolution is also presented in the $(\varepsilon_\alpha, \omega)$ state-space coordinates, with a good (smooth) behaviour and an entry with very low speed in the proximity of the final point. The same sampling control period as for the standard control algorithm was used: T = 2.456 ms, according to the same multicriterial optimum. It is confirmed the right operation of the 2 interrupts and the existence of quite large time reserve during each T for additional tasks. The diagram from the figure 14a concerns a quasi steady state regime, revealing the typical task distribution. Several values for the tasks time are precisely measured. Δt SPER = 2.456 ms << T_m = 50 ms (the electromechanical time constant of the motor); Δt PULSE = 125.5 μs - for a speed of 192 RPM. The last diagram caught the final algorithm time segment. The final detectable speed is 3.39 RPM. After the T2 timer (that marks the sampling rate and the cyclic processing for the control determination) is disabled, it can be seen a single pulse coming from the encoder. It is the ideal position error and the real too. Other durations are: Δt INT0 = 10 μs; Δt PROC = 558 μs < 25 % x T; Δt NORM = 310.5 μs; Δt LUT = 20.5 μs; Δt SAVES = 26 μs (globally). The most of time is necessary for the normalization arithmetic operations.

3 CONCLUSIONS

The sampling control period is more than additional tuning parameters for the digital control. The author conceived a multicriterial conditioning relation set with the limitation both for the upper and the lower values for the sampling period. The general timing proposed for the servodrive control is based on imbricate interrupts. A strong real-time constraint is accomplished by a hardware interrupt that makes an acquisition rate different than the control rate. The

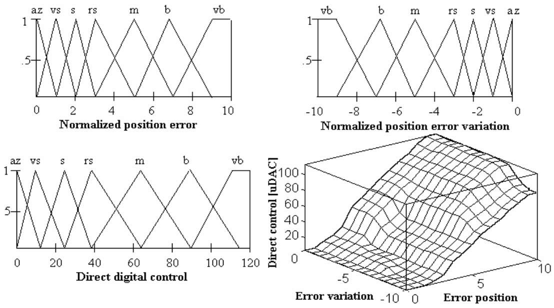


Figure 11: The basic elements for a LUT - FLC.

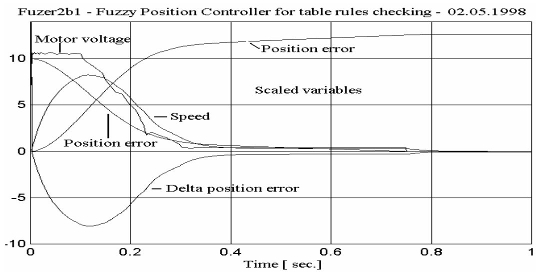


Figure 12: Results for a FLC in simulation.

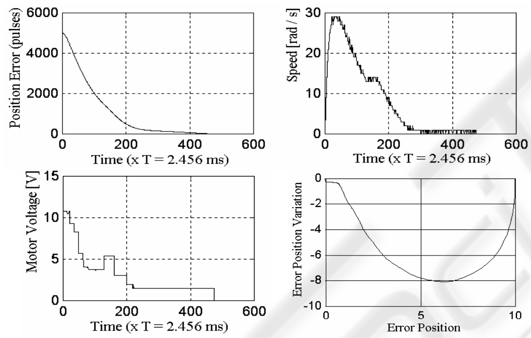
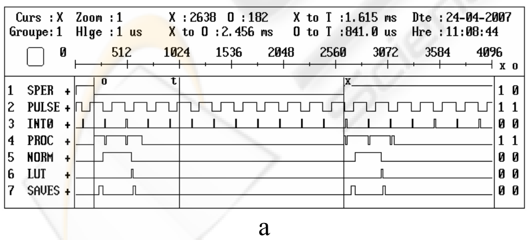
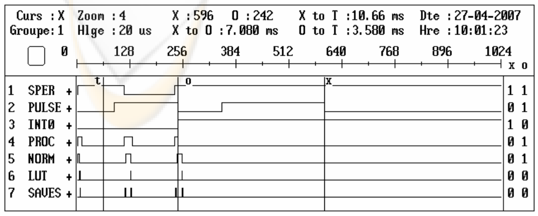


Figure 13: On-line results for a LUT based FLC.



a



b

Figure 14: The on-line recordings for a LUT FLC.

on-line results, both for the standard algorithm and the fuzzy control, are very good in terms of the macroscopic variables and for the timing revealed by on-line recordings with a logic analyzer. Some experiments proved that a good choice for the sampling control period is not necessarily related with a high end control processor but is the result for all correlations previously mentioned.

REFERENCES

Astrom, K.J., Wittenmark, B., 1997. *Computer-controlled systems: theory and design*, Prentice Hall, USA.

Coleman C. P., Godbole D., 1994. A Comparison of Robustness: Fuzzy Logic, PID and Sliding Mode Control, *Proc. of the American Control Conference*, pp. 1654-1659.

Do Wan, K., Jin Bae, P., Young Hoon, J., 2007. Effective digital implementation of fuzzy control systems based on approximate discrete-time models, Automatica *(IFAC Jour.)*, Volume 43 , Issue 10, pp. 1671-1683.

Ibbini, M.S., Jafar, A.S., 2002. Self-Tuning Fuzzy Logic Controller for a Series DC Motor, Proc. *(369) Power and Energy Systems,* Acta Press.

Kozek, M., Lorenz, A., Kampas, Ph., 2007. Modeling and control of an electric servo drive with strong restrictions in the control variable, *Int. Journal of Applied Electromagnetics and Mechanics*, Vol. 25, Number 1-4, pp. 521 – 527.

Mihai, D., Constantinescu C., 1999. Fuzzy Versus Standard Digital Control for a Precise Positioning System with Low-Cost Microcontroller*, PCIM99*, Nurnberg, Proceedings, pp. 249-255.

Mihai, D., 2004. *Systèmes d'entraînements électriques I. Problèmes fondamentaux. Systèmes avec moteurs à courant continu*, Ed. Universitaria, Craiova.

Mihai, D., 2006a. Additional Mathematical Pre-processing for the Fuzzy Control of a Servodrive, *WSEAS Trans. on Circuits and Systems*, Is. 11, Vol. 5, pp. 1575-1580.

Mihai, D., 2006b. An Optimized Fuzzy Control Algorithm for Servodrives. Some Real-Time Experiments. *Proceedings, IS '06,* London, paper 1-4244-0195-X/06-CD ROM, pp. 192-197.

Mrozek, B, Mrozek, Z., 2000. Modelling and Fuzzy Control of DC Drive, *ESM 2000*, Ghent, pp186-190.

Silveira, P. E., Souza, J.R., Biazotto R. de, V. M., 2002. Speed Control of an Autonomous Mobile Robot: Comparison between a PID Control and a Control Using Fuzzy Logic, *J. Braz. Soc. Mech. Sci*., vol.24, no.2, pp.127-129.

Vas, P., 1999. *Artificial-Intelligence-Based Electrical Machines and Drives*, Oxford University Press.

*** Technosoft S. A., 1997, *MCK 240 DSP Motion Control Kit*. User Manual, Switzerland.