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DATA COMPRESSION METHODS FOR THE RECORDING OF INDUSTRIAL ROBOTS TRAJECTORIES

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ABSTRACT

The data compression problem is of signifiant importance for spray-painting robots where the amount of information describing trajectories must be reduced in order to increase the storing capabilities of the system memory. The proposed methods-original ones-are suitable for real time recording by cheap computer systems such as 8-bit micros. These methods are of two types :

- recursive modelling methods by means of straight segments
- binary encoding

These methods were investigated by the CERT together with the AOIP Firm, and applied to A.K.R. spray painting robots.

INTRODUCTION

Given a low frequency signal, human originated, sampled and digitalized, we want to find an encoding method such that : - the memorized information will be more compact than the original one. - the reconstituted signal will be very close to the original one (a relative precision of a few thousanths in the bandwidth of the given signal). - and at last, such that its implementation is simple and not too much time consuming on a microprocessor (some microseconds per measurement).

In this paper we present two methods which solve this problem :

- A model of the trajectories,made of straight segments with a limited maximum error. An unpublished recurrent method has been developped for this study because the least mean square error model results in too lenghthy computations.

- A model based on binary encoding. This method is also unpublished and is in every aspect well adapted to the problem : rate of compression, computing efficiency, precision.

I - PIECEWISE - LINEAR MODELLING

The trajectory to be modelled is divided in portions which can be approximated by straight segments. Two mains problems are to be solved :

. détermination of the coordinates of the segments ends.
. evaluation of the parameters of the straight line representing each portion.

These two computations must be carried out in real time. In other words, the modelling of the trajectory is to be done as the points of this trajectory become available. Any method requiring the storage of a set of points of this trajectory, to be globally processed eventually, is a priori discarded because of the computing time and memory core drastic requirements.

We will present two methods for computing the parameters of straight segments.

I.1 - Recursive least square method

This method is a very classical one. We present figure 1 an example of flowchart:

ε is the predicted error - J is the error criterion - A is the slope of the least square line - B is the origin ordinate - E is the mean error threshold.

The coefficients a_M, b_M, j_M are :

$$a_M = \frac{6}{M(M+1)} \qquad b_M = \frac{2}{M} \qquad j_M = \frac{(M-1)(M-2)}{M(M+1)}$$

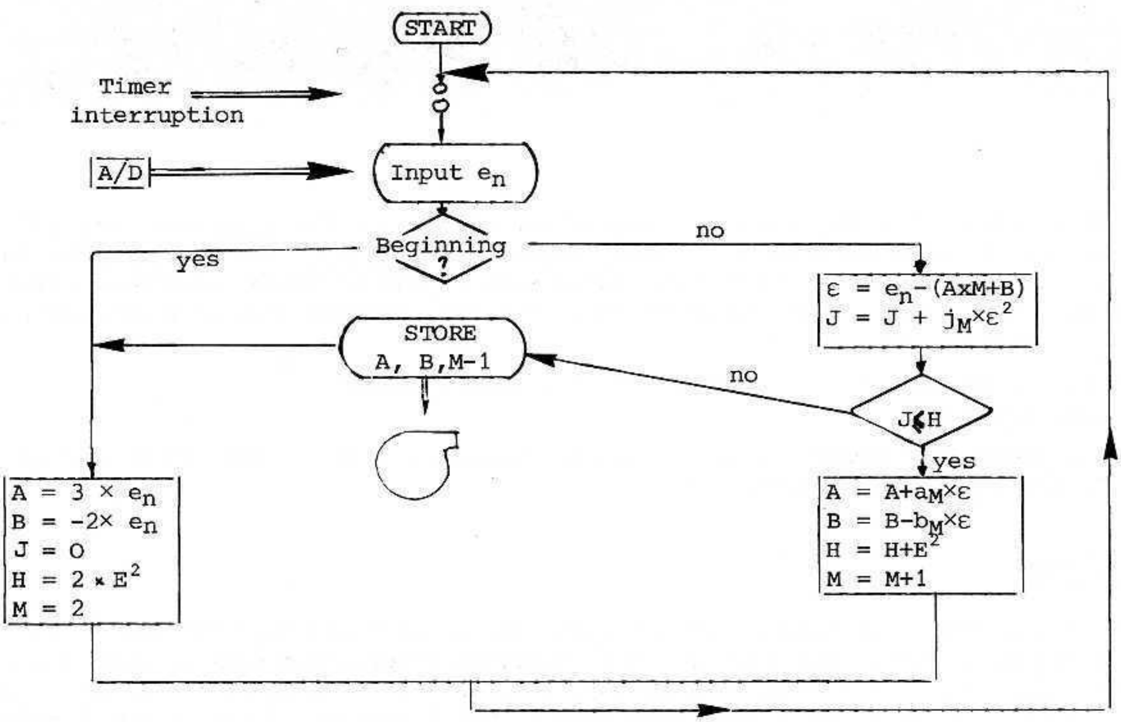

Figure 1 : Example of flowchart for the recursive least square method

The so calculated mean square lines offer only a limited guarantee for the precise duplication of the trajectory. The errors at the ends of the segments are large. Hence there are significant discontinuities at the junction points and troublesome transient behavior of the modelled signal.

I.2 - Bounded error piecewise linear modelling (BEPL)

Figure 2 represents the results we obtain in modelling a given signal either by least square (case a) or by a piecewise linear trajectory which always remains inside a chosen precision gauge (case b). The least square modelization shows a good global dispatching of the error however there are discontinuities at the junctions points. The bounded error piecewise line (BEPL) presents sometimes badly dispatched errors but limited by the chosen threshold, and preserves the signal continuity.

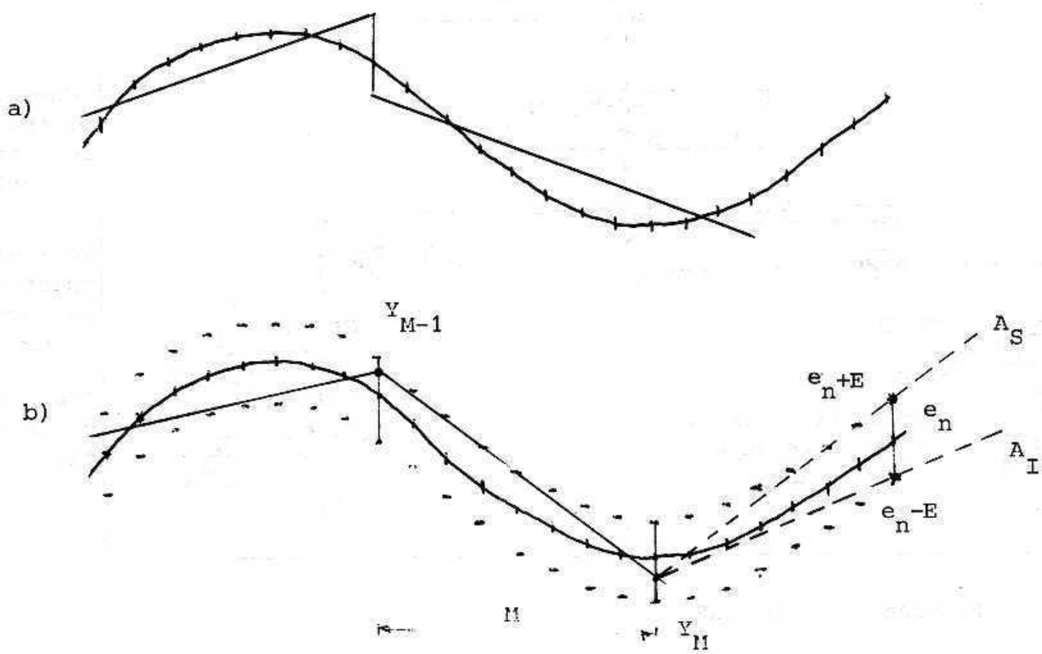

Figure 2 : Piecewise linear modelling - a) least square
b) bounded error

The presented recursive algorithm computes the breakpoints Y_M and the number of intervals M between these points. The principle of the computation consists in computing the successive intersections of angular sectors defined as follows: the vertex is the last breakpoint Y_M and the chord is the vertical tolerance segment at the current point (e_n+E, e_n-E). When the intersection becomes empty we determine a new breakpoint Y_{M+1} whose abscissa is that of the previous current point e_{n-1}.

II - BINARY ENCODING

The O,1 encoding is a method where the value e_n of the digital signal is changed into a O-1 bit representing a bang-bang variables $W_n \in \{-E,+E\}$

The most known method is the Deltamodulation found in 1946 by E.N.Deloraine, S.Van Merlo and B.Derjavitch (brevet d'invention n°932 140- 10 août 1946 - France, page 140) We will call it "First order binary encoding" because it requires "one" integration in the signal reconstruction process. The success of these methods stem from the use of digital integration which involves no signal drift as opposed to analogical integration.

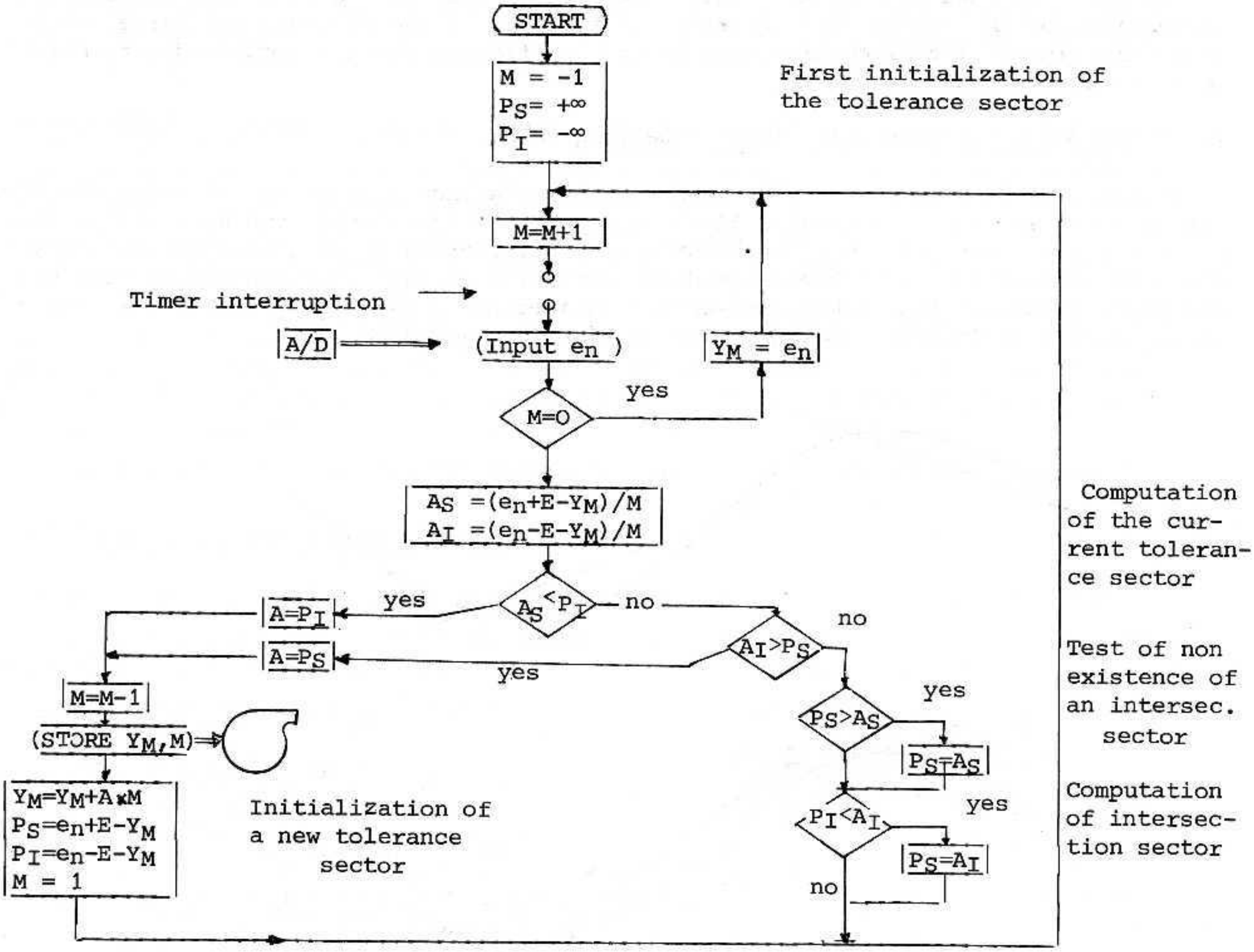

Figure 3 : Flowchart of the BEPL

II.1 - First order binary encoding

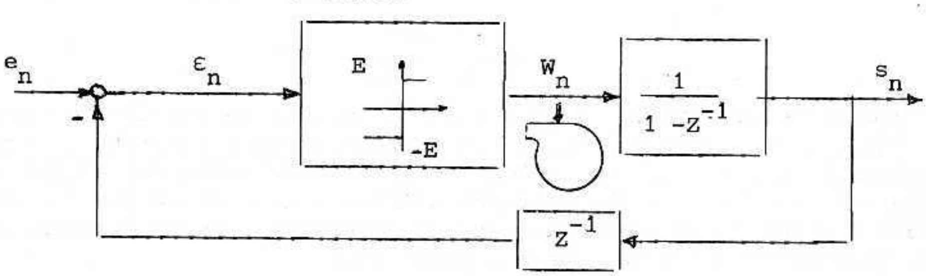

Figure 4 : First order binary encoder

The block diagram of the encoding system is shown in figure 4. The z^{-1} operator is the T delay operator (T : sampling period). An example of this first order binary encoding is illustrated in figure 6 (case a). This example brings to light the following facts :

- the slope of the s_n signal is bounded by E in absolute value. This value must be larger than the maximum evolution speed of the e_n signal so that the s_n signal can always follow it.
- when the e_n signal is approximately constant, the s_n signal is periodic with period 2T and the peak to peak amplitude is equal to E.

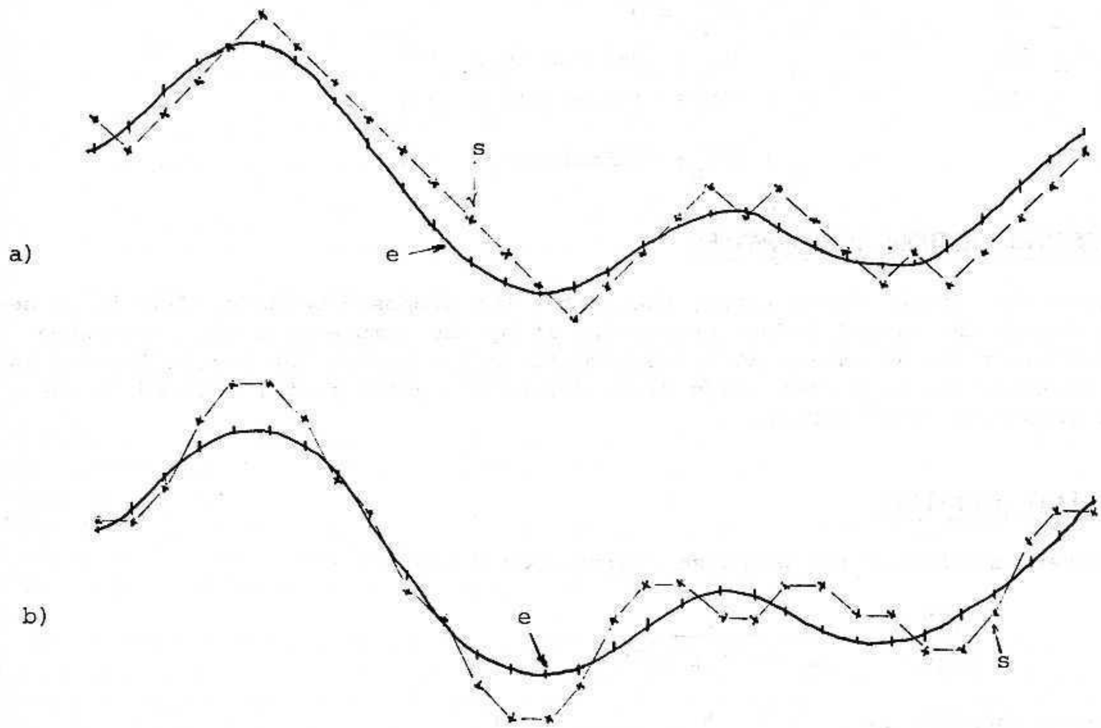

Figure 5 : Binary encoding
a) - First order
b) - Second order without compensation

Generally this method does not allow to simultaneously satisfy the precision requirements and dynamical constraints.

II.2 - Pseudo optimal second order binary encoding (COBIPSO)

A drastic improvement over the previous method consists in using a double integration for the reconstruction of the s_n signal. The COBIPSO method is presented figure 6. In order to accurately follow the input signal s_n we use a digital compensator. We take as binary signal for W_n the sign of the switching curve expression:

$$\varepsilon_n + \frac{V_n}{2} \left(\frac{|V_n|}{E} + 1 \right) = 0 \qquad (1)$$

This curve is obtained by translating the phase trajectories leading to the origin, in order to reduce the overshoots due to the switching delays.

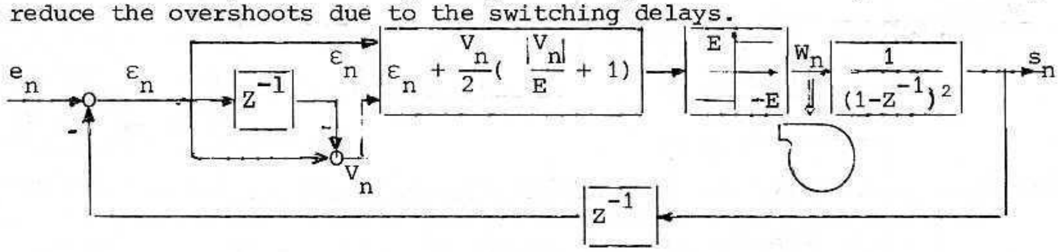

Figure 6 : COBIPSO

To reduce the noise sensibility of the method one can compute v_n by

$$v_n = (s_{n+1} - s_{n-1})/2 - (y_{n-1} - y_{n-2})$$

When the computing time to evaluate expression (1) is too large one can substitute to this expression the following piecewise linear approximation :

$$|\varepsilon_n| \leq 6E \rightarrow \varepsilon_n + 2V_n = 0$$

$$6E < |\varepsilon_n| \leq 78E \rightarrow \varepsilon_n + 8V_n + 18E \times \text{sign}(\varepsilon_n) = 0$$

$$78E < |\varepsilon_n| \leq 190E \rightarrow \varepsilon_n + 16V_n + 114E \times \text{sign}(\varepsilon_n) = 0$$

$$190E < |\varepsilon_n| \rightarrow \varepsilon_n + 32V_n + 418E \times \text{sign}(\varepsilon_n) = 0$$

III - COMPRESSION METHODS PERFORMANCES

The larger the signal/noise ratio, the better the proposed methods. Thus it is necessary to filter the signal before processing it by the compression algorithm when the signal/noise ratio is small. An analogical filtering before the digitalization is always preferable. Its high cost leads us to define a digital filter adapted to the problem of recording trajectories.

III.1 - Digital prefilter

The transfer function of the proposed digitalized filter is :

$$\frac{F(Z)}{E(Z)} = \frac{1}{8 - 11Z^{-1} + 4Z^{-2}}$$

Its recurrent equation is :

$$f_n = (e_n + 11\, f_{n-1} - 4\, f_{n-2})/8$$

Beyond its easy implementation this filter offers the following advantages :

- no static error
- critical damping ($\xi = 0.83$)
- natural frequency = 1/15 sampling frequency
- the phase shift is a pure delay of three sampling periods over the frequency bandwidth to be respected.

This last point is very important in order to synchronize the six joints of the robot.

III.2 - Test signal

In order to compare these compression methods we have used a signal which represents the painting trajectories. The figure 7 shows hows this signal was generated :

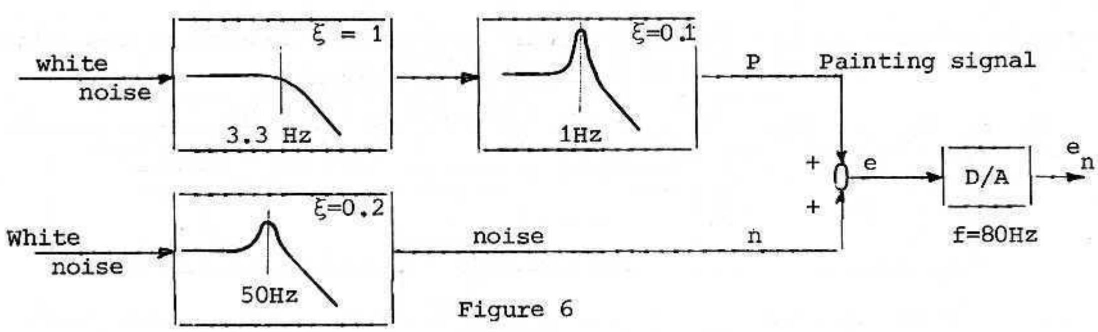

Figure 6

III.3 - Test results

We only present the results for the BEPL compression method (reconstructed signal y) and the COBIPSO method with the switching curve approximated by straight segments (reconstructed signal s). The results are summed up in the figure 7 :

σ_p/σ_n	43 dB (140/1)	29 dB (28/1)	23 dB (14/1)	Entry
$\sigma_p/\sigma_{(p-f)}$	40 dB (110/1)	38 dB (80/1)	34 dB (48/1)	Prefilter
$\sigma_p/\sigma_{(p-y)}$	33 dB (46/1)	33 dB (44/1)	32 dB (40/1)	BEPL
$\sigma_p/\sigma_{(p-s)}$	40 dB (98/1)	37 dB (74/1)	34 dB (49/1)	COBIPSO

Figure 7 : test results (signal/noise ratio)

- The first line give the ratios painting signal/noise for the three presented tests
- The second line presents the ratios painting signal/error after the digital prefiltering (p - f)
- The third line presents the ratios painting signal/reconstruction error (p - y) for the modelling with the BEPL
- The fourth presents the same ratios for the COBIPSO method.

The compression rate of the binary encoding is equal to the number of bits necessary for the digitalization of the signal to be modelled. The compression of the BEPL method depends on the value of the allowed error. In the presented table, this gauge is such that the obtained compression rate was approximately the same as by the COBIPSO method for the carried out test. The proposed comparison is therefore significant of the performances of these two methods.

- It can be noticed that the digitalized prefilter is useless when the signal/noise ratio is greater than 40 dB
- The BEPL method is clearly worse than COBIPSO when the residual noise level is small
- COBIPSO does not really deteriorate the signal/noise ratio.

Without a digitalized prefilter, performances rapidly deteriorate as the noise grows, for example for COBIPSO the signal/noise ratios becomes 37 dB, 20 dB and 10 dB.

IV - CONCLUSION

The data compression methods for the recording of trajectories of industrial robots must have the following properties :

- reduced amount of computation for the recording and for the reconstruction of the trajectories
- reduced memory storage requirement
- weak modelling error
- smooth reconstructed model.

The COBIPSO method has all these advantages. The BEPL too except the smoothness. Moreover the COBIPSO method allows a constant compression rate independant of the signal. This method have been validated on the spray painting robot of the A.K.R. Presently the data compression system used on these robots is based on an improved binary encoding method suggested through the present study.