The assembler performs two passes, checking the syntax of the assembler language instructions and constructing a symbol table on the first pass, and converting the instructions into object code on the second. All syntax or other coding errors are printed out and counted, causing termination of the assembler with an appropriate message. The new package, while different from the previous one [1] in many details, is nevertheless fully compatible with it. Only the new assembler is necessary to expand the programming capabilities of the former package from an 8008 to an 8080–8008 based system.

The programs are written in HP Basic for use on an HP 2100F time shared computer system. It is expected that the package will perform well with only slight modification on any Basic system which offers extended file management.

Conclusion

A system for programming an Intel 8080 microcomputer using a basic time shared system has been reported. The cross assembler is fully compatible with previously reported software [1]. The final output may be loaded directly into RAM for program execution. Copies of the software package are available to interested readers upon request.

References

[1] D. E. Dawson and E. A. Parrish, Jr., "A programming system for a microcomputer using a time-shared computer," *IEEE Trans. Instrum. Measure.*, vol. IM-24, pp. 272–273, Sept. 1975.

Comments on "Methods, Statistics, and Theory of Delay Calibration"

ZSÔLT PÁPAY

Introduction

In the above paper,[1] some theorems are derived for the direct mean-estimation with time-interval quantization. These results are valid in a wider sense and at the same time—as we point out briefly—they are special cases of a more general description using the quasi-statistic model[2] of the analog-to-digital converter (ADC).

Quasi-Statistic Model of ADC

The ADC, by means of sampling, quantizing, and coding, designates the interval (channel) in which its input lies. Consider globally uniform quantizing with resolution Δx (see Fig. 1) and use *normalized* variables $W = X(\Delta x, n = H_Q)\Delta x = N - W$, where the input $W = w$ is actually real and the output $N = i$ integer. For a practical ADC only the probability of i, given $W = w$, $\Pr\{i \mid W = w\}$ can be specified. So, in a *one-dimensional* case and if the operation is free of saturation, the conditional distribution of N is given by

$$P(i|w) = \lim_{\epsilon \to 0} \Pr\{i \mid w < W \leq w + \epsilon\} = \frac{P(i,w)}{p_W(w)}$$

hence, for general description of the ADC, the *joint* distribution and characteristic function (CF) are

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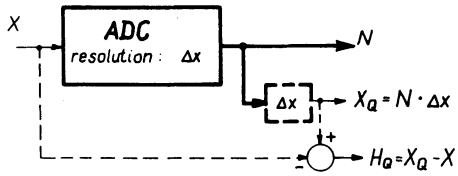

Fig. 1.

$$P(i,w) = P(i|w) \cdot p_W(w)$$

$$\updownarrow$$

$$\rho_{N,W}(u_1,u_2) = \int_{-\infty}^{\infty} dw \sum_i P(i,w) \cdot \exp[j(u_1 i + u_2 w)] \quad (1)$$

where $p_W(w)$ is the density-function of the input, and $\Sigma_i P(i|w) = 1$. Assuming $N = i$, we define the following function of w as the *channel profile* $P(i|w) = P_i(w)$. It is independent of the input distribution and can be estimated for an actual ADC (for example with relative-frequency measurements).

A simpler—and often sufficient—estimation is the use of *quasi-statistic* model. We assume identical $P_i(w) = P_\kappa(w - i)$ channel profile forms for all i, or with a new variable $z = w - i$

$$P_\kappa(z) = P_i(i + z).$$

Define

$$\phi_\kappa(u) = \int_{-\infty}^{\infty} P_\kappa(z) \cdot \exp(-juz)\, dz \leftrightarrow P_\kappa(z)$$

$$= \frac{1}{2\pi} \int_{-\infty}^{\infty} \phi_\kappa(u) \cdot \exp(juz)\, du \quad (2)$$

furthermore, using $p_W(w) \leftrightarrow \rho_W(u) = E[\exp(juw)]$, from (1) we have

$$\rho_{N,W}(u_1,u_2) = \sum_k \rho_{W,W}(u_1 + 2\pi ck, u_2) \cdot \phi_\kappa(u_1 + 2\pi k)$$

$$\updownarrow$$

$$P(i,w) = \frac{1}{(2\pi)^2} \int_{-\pi}^{\pi} du_1 \int_{-\infty}^{\infty} du_2\, \rho_{N,W}(u_1,u_2) \cdot \exp[-j(u_1 i + u_2 w)] \quad (3)$$

$k = 0, \pm 1, \cdots$. This is the fundamental equation for the quasi-statistic model of ADC, where $\rho_{W,W}(v_1,v_2) = \rho_W(v_1 + v_2)$ is the input CF and the ADC is a "black box" with specified (measurable, or computable by a mathematical model) $P_\kappa(z)$. Now, using the well-known methods: the *moment theorem* and so on, the necessary statistics can be generated from (3). For example, the ADC output CF is:

$$\rho_N(u) = \rho_{N,W}(u,0)$$

$$= \rho_W(u) \cdot \phi_\kappa(u) + \sum_{k \neq 0} \rho_W(u + 2\pi k) \cdot \phi_\kappa(u + 2\pi k) \quad (4)$$

and clearly, in the "q-limited" practical case ($\rho_W(q) \approx 0$, if $|q| \geq 2\pi$) we can use the additive model for the moment generation; the CF of the error of ADC is $\rho_n(u) = \rho_{N,W}(u,-u)$; etc. Note, for dimensional quantities, we obtain formulas with simple linear transformations ($W \leftarrow X$; $N \rightarrow X_Q$, $n \rightarrow H_Q$). Assuming a specific $P_\kappa(z)$, we have—as a special case—the generally used *deterministic model*[3] of ADC.

Channel Profile and Corollaries

In the case dealt with in the above paper[1] (Fig. 2), with $w = d/T$, $h = x_1/T$, we have

[1] D. J. Torrieri, *IEEE Trans. Instrum. Meas.*, vol. IM-24, p. 96, June 1975.

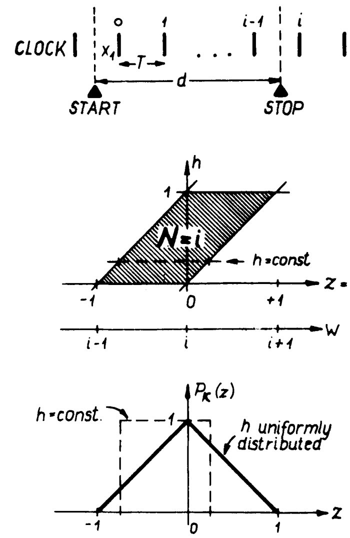

Fig. 2.

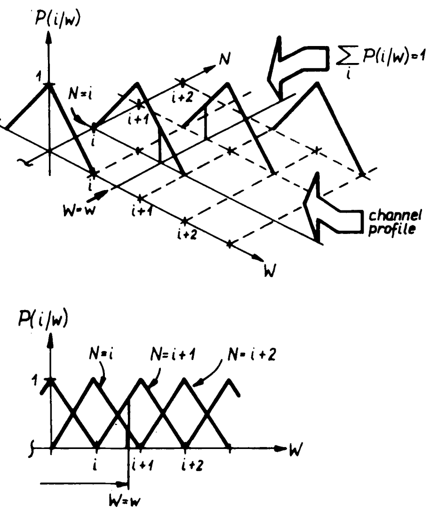

Fig. 3.

TABLE I
Normally Distributed ($m = i, \sigma_w$) Input

σ_w	Relative Error (in percents) for Approximation of var(N) with Torrieri's (58) [var(N) $\approx \sigma_w\sqrt{2/\pi}$]	Additive Model [$\epsilon = 0$]
0.25	−0.004	
0.3	−0.056	
0.35	−0.31	
0.40	−0.99	1.3
0.41	−1.2	1.1
0.42	−1.4	0.91
0.43	−1.7	0.75
0.44	−1.9	0.62
0.45	−2.2	0.51
0.5		0.18
0.55		0.055
0.6		0.016
0.65		0.004

$$N = i, \quad \text{if } -1 < z - h < 0, \quad 0 < h < 1$$

and because the probabilities of equivalent events are equal

$$P_\kappa(z) = \Pr\{z < h < 1 + z\}.$$

The channel profile (and so the effect of ADC) is strongly related to the start-error component h (we assume that h is statistically independent of z). To obtain $P_\kappa(z)$, some kind of *hypothesis* consistent with the practical case is necessary; for example, h = constant (if clock and start are synchronized), or h is a random variable with known distribution.

If specifically[1] h is uniformly distributed on (0,1), then $P_\kappa(z)$ has a triangle form (Figs. 2 and 3), and from (2)

$$\phi_\kappa(u) = \left[\frac{\sin(u/2)}{u/2}\right]^2 = 2\,\frac{1 - \cos(u)}{u^2}.$$

(Note, we get the same result, for example, for a deterministic ADC with uniform dither.)

Now, with $E(w) = m$ and var $(w) = \sigma_w{}^2$, from (4) we easily conclude that the mean is bias-free: $E(N) = m$ (see Theorem 1 of Torrieri[1]), and

$$\text{var}\,(N) = \sigma_w{}^2 + \frac{1}{6} - \epsilon$$

where

$$\epsilon = \frac{1}{2\pi^2} \sum_{k \neq 0} \frac{1}{k^2}\, \rho_W(2\pi k) = \frac{1}{\pi^2} \sum_{k=1}^{\infty} \frac{1}{k^2} \operatorname{Re}\,[\rho_W(2\pi k)]$$

Re [·] denotes the real part (see also the Appendix). Let $\tilde{\rho}_W(u)$ the CF of the zero-mean variable: $\rho_W(u) = \tilde{\rho}_W(u) \cdot \exp(jum)$; if the distribution of w is symmetric on m, that is $\tilde{\rho}_W(u)$ is real (and even), then

$$\epsilon = \frac{1}{\pi^2} \sum_{k=1}^{\infty} \frac{1}{k^2}\, \tilde{\rho}_W(2\pi k) \cdot \cos(2\pi k \cdot m)$$

and this is periodic, because $m = i + r$, where $0 \leqslant r < 1$ (see Turrieri's[1] Theorems 3 and 4). For a normally distributed input $\tilde{\rho}_W(u) = \exp(-\sigma_w{}^2 u^2/2) > 0$, so var (N) is a minimum when $r = 0$ and see Table I.

For any other form of $P_\kappa(z)$ one can proceed similarly. Generally, the mean-estimation is bias-free only if $\phi_\kappa(0) = 1$, $\phi_\kappa(2\pi k) = 0$ $(k \neq 0)$, and $\phi_\kappa'(2\pi k) = 0$.

Appendix

In the "q-limited" case $\epsilon \approx 0$, and generally: $1/6 > \epsilon > -1/12$. That is, we may write

$$\epsilon = \int \rho_W(w) \cdot g(w)\, dw, \quad \text{where } g(w) = \frac{1}{\pi^2} \sum_{k=1}^{\infty} \frac{1}{k^2} \cos(2\pi k \cdot w).$$

Let $r = w - [w]$, where the square brackets denote the "greatest integer in," hence $g(w) = g(r)$. Since[4]

$$\sum_{k=1}^{\infty} \frac{\cos(k\theta)}{k^2} = \frac{\pi^2}{6} - \frac{\pi\theta}{2} + \frac{\theta^2}{4} \qquad 0 \leqslant \theta < 2\pi$$

we obtain the above inequality. Alternatively, we can also make use of the fact that $g(r)$ is the Fourier expansion of $B_2(r) = r^2 - r + 1/6$ Bernoulli polynomial, $0 \leqslant r < 1$.[5]

Note: With r = rem (w), we obtain Theorem 2 Torrieri's cited paper[1].

[2] Zs. Pápay: "The channel profile of time-interval quantization," *Mérés és Automatika* (Hungary), vol. XXIII, p. 46, 1975, and "Quasi-statistic model for estimating the effect of ADC," to be published in *Hiradástechnika* (Hungary).

[3] See, for example, G. A. Korn, *Random-Process Simulation and Measurements.* New York: McGraw-Hill, 1966, ch. 6.

[4] *Handbook of Mathematical Functions*, pp. 1005, NBS, May 1968.

[5] *Handbook of Mathematical Functions*, pp. 804, NBS, May 1968.