A microprocessor-based real-time BASIC random interstimulus interval generator with different probability density functions

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A low-cost random interstimulus interval (ISI) generator with different probability density functions is described. The frequency histograms of the output ISIs are uniformly, normally, exponentially, and binary distributed functions.

Recent developments in microprocessor technology and related peripheral interfacing (PIA) technology make real-time randomization of an external stimulus device inexpensive (see Brown & Deffenbacher, 1978; Kashinsky, Romanczyk, & Treiber, 1979; Milkman, Shapley, & Schick, 1978; Perera, 1978; Polson, 1978; Santa & Streit, 1978; Sidowski, 1978).

A low-cost circuit for a quasirandom interstimulus interval (ISI) generator using shift registers has been described by Damashek (1976) and Osaka (1978a, 1978b). Randomization techniques based on pseudo-random number generation (Jansson, 1966) have been written in assembly (Grieser, 1977; for 8080 and 6800 CPUs), BASIC (Lehman, 1977; Nilsson, 1978; Robertson, 1977), and FORTRAN (Green, 1977).

Using the Commodore PET 2001 microcomputer as a random number generator, visual and auditory stimuli can easily be signaled with random ISIs having different probability density functions.

In the system described here, the PET communicates with two LEDs and an 8-ohm speaker via 6522 PIA (VIA) I/O ports, as shown in Figure 1 (see McLean, 1978; Yob, 1979a, 1979b, for the PET's port handling techniques; see also Commodore Business Machines, Inc., 1978, Note 1; PET User Group, 1978). Only PA5, PA6, and CB2 ports are defined as output modes. Figure 2 shows a general flow chart for the random ISI generator written in BASIC, as shown in Figure 3.

PROGRAMMING

As shown in Figures 2 and 3, after initialization (Lines 10-30), the experimenter inputs the tone duration, ISI factor, random number generator subroutine select (Lines 32-50), print select (to the 9-in. CRT), and ISI unit select (either 100-msec or 1-sec step ISI) sequentially. After finding these input values, the PET generates random ISIs with selected random ISI fre-

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Figure 1. An interfacing logic for the random ISI generator.

quency: uniformly (UNIF), normally (NORM), exponentially (EXP), and binary (BIN) distributed frequency and randomization (RNDMZ) without replacement.

UNIF (Lines 1000-1140)

Using PET BASIC, uniformly distributed random numbers ranging from 1 to 10 can be obtained easily (Line 1050). The scale factor YY (Line 1053) determines the size of the mean ISI.

NORM (Lines 2000-2165)

Using a central limit theorem, the random numbers with normal distribution are obtained from a series of uniform random numbers by the formula $R = [T/L - .5] / \text{SQRT}[1/(12 \cdot L)]$, where T indicates a sum of uniform random numbers up to L. If L = 12, the above formula is simplified as $[T - 6]$. The size of L and N (sample size) determines normality of the distribution function.

Figure 2. A general flow chart for the random ISI generator.

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----- MAIN PROGRAM -----
10 DIM X(255)
15 PRINT"6522 PIA OUTPUT PORTS DEFINED AS:"
18 PRINT"RANDOM PULSE=/J:PA5/K=PA6;TONE=/M:CB2":GOSUB6222
20 PRINT"CLIP":GOSUB6600
25 PRINT"MEMORY USED="7167-FRE(0)"BYTES"
30 PRINT"REAL TIME BASIC RANDOM ISI GENERATOR"
32 PRINT"TONES=":INPUTXX
35 PRINT"ISI FACTOR=":INPUTYY:FF=0
36 A=59459:B=59464:C=59466:D=59467:E=59471
37 POKEA,96:POKEB,0:PRINT"CLIP"
40 PRINT"RND/SELECT:UNIF=1/NORM=2/EXP=3/BIN=4/RNDMZ=5"
50 INPUTL:ONLGOSUB1000,2000,3000,4000,5000
60 GOT020
70 END

----- RANDOM UNIFORM SUBROUTINE -----
1000 PRINT"CLIP":PRINT"RND/RANDOMIZATION"
1020 PRINT"SAMPLE SIZE=":INPUTN
1030 GOSUB6100:M=0:P=0:MN=0
1040 TIS="000000":GOSUB7600
1050 R=RND(1):L=INT(R*10)+50
1053 KL=INT(R*YY)
1055 GOSUB7500
1057 FF=FF+1
1058 IFFF>NTHEN1080
1060 X(L)=X(L)+1:M=M+R:P=P+R*R
1070 IFQ<1GOTO1077
1075 PRINTFF,R,"ISI="KL
1077 GOT01050
1080 MN=M/N:V=P/N-MN*MN
1090 SD=SQR(V):PRINT:GOSUB6000
1095 PRINT"RNDUNIF"
1100 PRINT"N="N:PRINT"MEAN="MN:PRINT"VAR="V
1110 PRINT"SD="SD:PRINT"TIME="TIS:PRINT
1120 GOSUB6000:GOSUB6500
1130 GOSUB6000:GOSUB6200
1140 RETURN

----- RANDOM NORMAL SUBROUTINE -----
2000 PRINT"CLIP"
2010 PRINT"RND/NORMAL DIST./CENT.LIM.THEOREM"
2020 PRINT"R=(T/L-0.5)/SQR(1/(12*L))"
2030 PRINT"SAMPLE SIZE=":INPUTN:PRINT"TIME=":INPUTL
2035 V=0:P=0:W=1
2040 GOSUB6100:TIS="000000":GOSUB7600
2050 T=0:FORJ=1TOL:X=RND(1)
2060 IFQ<1THEN2070
2065 PRINTJ,"X="X
2070 T=T+X:NEXTJ
2075 R=(T/L-0.5)/SQR(1/(12*L))
2080 IFQ<1GOTO2090
2085 PRINTTAB(15)"R="R
2090 Y=Y+R:P=P+R*R:A=INT(R*10)+50:PRINT"KL="KL:A*YY:GOSUB7500
2100 IFQ<1GOTO2110
2105 PRINTTAB(18)"A="A,TAB(20)"I="I,W,"ISI="KL
2110 X(A)=X(A)+1:W=W+1
2120 IFW>NTHEN2130
2125 GOT02050
2130 MN=Y/N:V=P/N-MN*MN:SD=SQR(V)
2135 GOSUB6000:PRINT"RNDNORM"
2140 PRINT"N="N:PRINT"MEAN="MN:PRINT"VAR="V:PRINT"SD="SD:PRINT"TIME="TIS

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2150 GOSUB6000:GOSUB6500
2165 GOSUB6000:GOSUB6200:RETURN

----- RANDOM EXPONENTIAL SUBROUTINE -----
3000 PRINT"CLIP"
3010 PRINT"RND/EXPONENTIAL DIST./F(X)=A*EXP(-A*X)"
3020 PRINT"SAMPLE SIZE=":INPUTN
3025 Y=0:P=0
3030 GOSUB6100:TIS="000000":GOSUB7600
3035 FF=FF+1:IFF>NTHEN3080
3040 X=RND(1):R=-LOG(1-X)
3045 K=INT(R*10)+10:KL=K*YY
3070 X(K)=X(K)+1:Y=Y+R:P=P+R*R
3075 GOSUB7500
3076 IFQ<1GOTO3078
3077 PRINTFF,R,"ISI="KL
3078 GOT03035
3080 MN=Y/N:V=P/N-MN*MN:SD=SQR(V)
3085 GOSUB6000:PRINT"RNDEXP"
3090 PRINT"N="N:PRINT"MEAN="MN:PRINT"VAR="V
3100 PRINT"SD="SD:PRINT"TIME="TIS:PRINT
3110 GOSUB6000:FORI=1TOL00:PRINTX(I);
3120 NEXTI:GOSUB6000:GOSUB6200
3130 RETURN

----- RANDOM BINARY SUBROUTINE -----
4000 PRINT"CLIP":PRINT"RND/BINARY":PRINT"SAMPLE SIZE=":INPUTN
4005 GOSUB6100:VC=0:YH=0:GZ=0
4010 TIS="000000":PRINT:GOSUB7600
4012 FF=FF+1:IFF>NTHEN4029
4013 X=INT(RND(1)+0.5):GZ=GZ+X
4015 KL=X*YY:IFKL<1GOTO4020
4018 GOSUB7500
4020 IFQ<1GOTO4025
4024 PRINTFF,X,"ISI="KL
4025 IFX<1THENYH=YH+1
4028 VC=N-YH:GOT04012
4029 GOSUB6000:PRINT"RDNBIN"
4030 PRINT"N="N:PRINT"MEAN="GZ/N
4040 PRINT"ZEROS="YH:PRINT"ONES="VC:PRINT"TIME="TIS:GOSUB6000
4050 PRINT"ZEROS=":FORJ=1TOYH:PRINT" ";NEXTJ:PRINT
4060 PRINT"ONES=":FORT=1TOVC:PRINT" ";NEXTT
4080 GOSUB6222
4090 RETURN

----- RANDOMIZATION SUBROUTINE -----
5000 PRINT"CLIP":PRINT"RND/RANDOMIZATION"
5005 PRINT"RND UP TO N (MAX:255)="
5010 INPUTN:PRINT"SESSION=":INPUTY:TIS="000000":GOSUB7600
5015 P=1:GOSUB6100
5020 FORI=1TON:X(I)=1:NEXTI:FF=0
5030 PRINT:PRINT"SESSION="P
5032 FF=FF+1:IFF>NTHEN5056
5035 R=INT(RND(1)*N)+1
5040 IFX(R)=OTHEN5035
5042 KL=X(R)*YY:GOSUB7500
5044 IFQ<1GOTO5050
5045 PRINTX(R),"ISI="KL
5050 X(R)=0
5054 GOT05032
5056 P=P+1
5060 IFY<PTHEN5070
5065 GOT05020
5070 GOSUB6000:PRINT"RANDOMIZATION NUMBER UP TO N="N
5080 PRINT"SESSION NUMBER="Y:PRINT"TIME="TIS:GOSUB6000
5085 GOSUB6222
5090 RETURN

----- GENERAL SUBROUTINES -----
6000 PRINT:FORI=1TOL00:PRINT" ";NEXTI
6010 PRINT:RETURN
6100 PRINT"PRINT/YES=1:NO=0":INPUTQ
6110 RETURN
6200 PRINT"IF PLOT/PRINT=":INPUTJ
6205 PRINT"SCALE FACTOR=":INPUTH
6210 IFJ<1THEN6230
6215 FORI=1TOL00
6220 PRINTTAB(X(I)/H)" "TAB(35)I:NEXTI
6222 TH=T
6225 IFT1-TH>300THEN6230
6228 GOT06225
6230 RETURN
6500 FORI=1TOL00:PRINTX(I);
6510 NEXTI
6520 RETURN
6600 FORI=1TOL00:X(I)=0:NEXTI
6610 RETURN
7500 POKEA,96:TH=T-1
7502 IFT1-TH>ZZ*KLTHEN7506
7504 GOT07502
7506 POKEA,0
7510 POKEA,16:POKEB,123:POKEC,51
7520 FORI=1TOXX:NEXTI
7530 POKEB,0
7540 RETURN
7600 PRINT"ISI UNIT SELECT:100MSEC=1:1SEC=2":INPUTAA
7610 ONAAGOSUB7700,7800
7620 RETURN
7700 ZZ=6:RETURN
7800 ZZ=60:RETURN

```

Figure 3. An example program for real-time BASIC random ISI generator. Random ISIs having uniform (UNIF), normal (NORM), exponential (EXP), binary (BIN), and randomized (RNDMZ) distribution can be generated.

EXP (Lines 3000-3130)

The exponentially distributed random numbers using the method of inverse function are generated by the formula $R = -[\text{LOG}(1 - X)]$. (A log transformation is used on each uniform random number.)

BIN (Lines 4000-4090)

These binary (0 or 1) numbers result from the formula $X = \text{INT}(\text{RND}(1) + .5)$, where $\text{RND}(1)$ generates uniform random numbers.

RNDMZ (Lines 5000-5090)

This subroutine randomizes numbers up to N without replacement (Lines 5035-5040). The program appears suitable for real-time BASIC laboratory automatization (BLA), since the output signals can be applicable to drive external devices such as pulse motors up to Yth session. Careful attention is required because the time to draw and reject terms is slightly longer for the later trials due to the sampling without replacement algorithm. This can introduce unwanted variation in an ISI.

Mean, variance, and standard deviation are printed out. In addition, the dimension statement, such as $X(I) = X(I) + 1$, prints out the graphic output of each distribution if required.

In the general subroutines (Lines 6000-7800), the PET prints out the output ISI distribution on print request following input of a scale factor value (Lines 6200-6230). It returns to the main program after 5 sec (Lines 6225-6228). In the statements from 7500 to 7540, the I/O port PA5 and PA6 of the 6522 PIA are defined as output mode ($\text{POKE } E, 196 [= 64 + 32]$), and the formula $[TI - TM > ZZ * KL]^2$ determines the ISIs, where ZZ and KL show the ISI unit select parameter and the ISI factor, respectively. Immediately after the end of the ISI, a 1-kHz tone is sounded for a given duration (Lines 7510-7530).

OUTPUT

Figure 4 shows an example program for calibrating

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***** ISI CALIBRATION PROGRAM *****
10 PRINT"CL":PRINT"6522 PIA OUTPUT PORTS DEFINED AS:"
20 PRINT"COUNTER: START=C: PA0: STOP=D: PA1: RESET=E: PA2:
   GND=COMMON":PRINT
25 PRINT"ISI RANGE SELECT: 0: 1-1 SEC=1: 1-10 SEC=2":INPUTN
30 GOSUB200
40 K=K+1
45 PRINT"N="K
50 IFK>NTHEN100
60 ONHGOSUB500,600
75 GOSUB300:GOSUB400
78 PRINT"ISI="ZZ/60
80 POKEX,4:POKEK,0
90 GOTO40
100 PRINT"CL":GOTO25
190 END
200 X=59471:POKE59459,7:PRINT"N=":INPUTN
210 K=0:TIS="000000":RETURN
300 POKEK,1:POKEK,0
310 IF1-TIS>ZTHEN330
320 GOTO310
330 POKEK,2:POKEK,0:RETURN
400 TM=T1
410 IF1-TM>180THEN430
420 GOTO410
430 RETURN
500 ZZ=6*K:ZM=T1:RETURN
600 ZZ=60*K:ZM=T1:RETURN
```

Figure 4. An example program for calibrating ISI using digital precision counter.

Figure 5. An output ISI histogram of the UNIF distribution.

Figure 6. An output ISI histogram of the NORM distribution.

ISI using a digital precision counter incorporating a 100-kHz crystal oscillator. Gating of the counter is made via PA0 (start pulse), PA1 (stop pulse), and PA2 (reset pulse) ports. Since the unit of the TI parameter of the PET is 1/60 sec, the error ratio is less than 1% for each time setting. Figures 5, 6, 7, and 8 show output ISI histograms for UNIF, NORM, EXP, and BIN, respectively.

UNIF

In Figure 5, when $N = 10,000$ for each session, a uniformly distributed histogram is obtained. The vertical bar shows the standard deviation.

NORM

Figure 6 clearly shows a normally distributed frequency histogram. Note that the larger the size of the $\text{TIE}(=L)$, the shallower the tail of the normal distribution curve.

EXP

Figure 7 shows an exponentially distributed frequency histogram. The vertical bar shows the standard deviation.

Figure 7. An output ISI histogram of the EXP distribution.

Figure 8. An output ISI histogram of the BIN distribution.

BIN

Figure 8 indicates uniformly distributed zeros and ones over six sessions. The vertical bar shows the standard deviation.

RNDMZ

When $N = 255$, randomization without replacement requires 403 sec for each session (ISI unit select = 1).

In general, the random ISI frequency histograms show the random ISI generator to be useful for real-time BASIC laboratory automatization (BLA).

REFERENCE NOTE

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NOTES

1. Decimal coded addressed locations: A = direction register; B = Timer 2 register; C = shift register; D = auxiliary control register; E = output register without handshaking.

2. Since PET's TI parameter is a counter of 1/60-sec steps, a statement such as [TI*300] determines a 5-sec lapse of the time.

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