Note

Fiber Length Measuring System with a Digitizer and a Microcomputer*

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Abstract——A fiber length measuring system was constructed and totally examined. The system is consisted of a projecting apparatus and a digitizer connected with a 8-bit microcomputer. They are supported by softwares listed in this paper. Their functions are briefly summarized as follows. Fiber lengths are recorded both on a printer and on a diskette by means of tracing fiber images which projected on the digitizer. The recorded lengths in a sample lot are then processed to a mean, minimum and maximum length, variance, standard deviation, and frequency distribution of the length at 0.3 mm intervals. These statistical values, including a mean of fiber lengths, in respective samples are automatically plotted against tree ages. In addition, the frequency distribution at every annual rings are printed in a three-dimensional manner. This system was effective and accurate enough (resolution ca. 0.2 mm on a sample specimen) for measuring fiber length, and was able to be constructed at a reasonable price.

Introduction

Cell dimensions, especially fiber or tracheid lengths, have often been measured as a factor which evaluates wood and pulp qualities[1]. However, the convensional methods are time-consuming and tedious, forcing us to eye-strains, and troublesome data-calculations, etc. Another defect is that the methods are difficult to fit the streight line of a micrometer-scale to the fiber images correctly when they are curved. In other words, experimental errors might be considerably large in the convensional methods[2].

Recent development of electronics technology enables us to introduce new instruments for the measurement, and thus the method is gradually improved[3~8]. For example, a digitizer was introduced for measuring fiber lengh[6,7], and a Fiber Size Analyzer was also developed[8]. In the latter case, respective fiber lengths are obtained when the fibers are running through a capillary on which polarized light is illuminated. Although this method achieves rapid measurement

* This system, which tentatively calls FILMS (Fiber Length Measuring System), was used in ref 2) and the user's mannual was presented in ref 13).

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of fiber lengths, it cannot avoid the detrimental counting of overlapped or broken fibers. In addition, an expensive instrument is required for the method. This method, therefore, will be unsuitable for a specific purpose[2]. In these circumstances, we developed a fiber measuring system with a digitizer and a microcomputer, which was accurate enough, inexpensive and able to be handled by an unexperienced person.

Present paper describes the hardware systems for fiber lenght measurement, in addition to the softwares which developed for controlling the sytem. An instruction mannual for the system was already presented (in Japanese)[13].

Sample Preparation for Fiber Length Measurement

Wood pieces (match sized) were treated with equal parts of acetic acid and hydrogen peroxide (30%) at 60°C for 2 to 4 days according to Flanklin's method[9]. Two mounting methods were examined after the treated pieces were rinsed with tapwater over night.

First: they stained with a domestic dye (Simplikol; dark blue; Browns Heidtmann Inc.; West Germany) at 60°C for a day. After rinsed them with tapwater, the stained pieces were macerated by a glass lod, then fibers obtained were mounted on a slide glass with Apathy's gum syrup (equal parts of gum arabic, sucrose and water). This dye stained samples better than Safranin did.

Second: macerated fibers were directly spread on a Scotch Book Tape #845 and mounted on a frame for slidemounting after they had been air-dried. The frame was able to carry 25–100 fibers according to their length. The images were clearly recognized on the digitizer plane even if without staining, because of the edge effect caused by different refraction indices between the mercerated fibers and air. This simplified method was highly efficient in order to count normal tracheids of Sugi (*Cryptomeria japonica*). Shrinkage of the tracheids was almost negligible comparing to those in the former mounting method.

Image Projection Systems

The prepared specimen described above was put on a projecting system as shown in Figure 1. Figure 1a shows that the image was projected on a digitizer through a closeup photographing stage and a pair of mirrors set at right angle. This system was appropriate to obtain rather high magnification up to ca. 110 fold, while the projection-image obtained were rather dark.

On the other hand, Figure 1b shows that a slideprojector was fixed in downward direction on the top of a frame and the fiber images were directly projected on a digitizer. The projector was correctly adjusted its position by using a slide

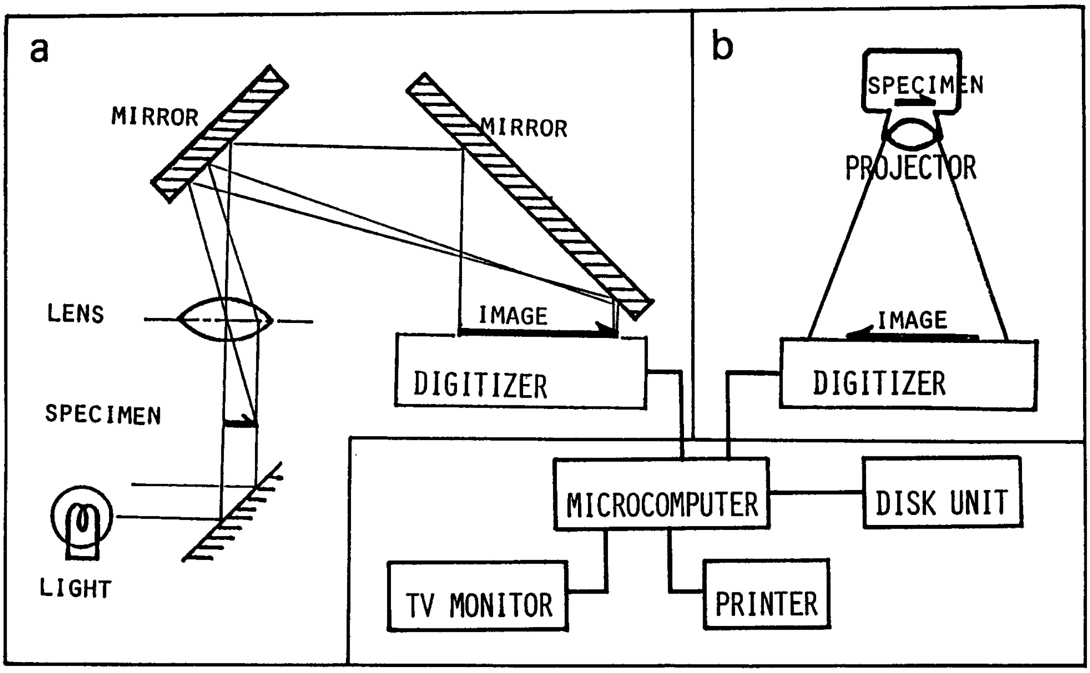

Fig. 1. Projection systems for the fiber images.
Left system (a) is suitable for large magnification, while right system (b) fits the projection of fiber images. Details see in the text.

Table 1. Optical characters of the lenses examined

Lens	f mm	N.A.	F	δ*
Splan 10X	18.98	0.30		1.12
Zuiko Macro	20		3.5	2.30
Splan 4X	36.16	0.13		2.58
Zuiko Macro	38		3.5	2.30
Cabin III	60		2.8	1.84
Splan 2X	73.42	0.08		4.19
Zuiko Macro	80		4.0	2.63

* $\delta=0.61\lambda/\mathrm{N.A.}=1.22\lambda F$ (μm/slit), where δ=resolving power, λ=wave length (540 nm), N.A.=numerical aperture, and F=F number. The optical characters of Cabin III (projector lens) show high resolution and brightness.

which ruled into regular squares. Thus, negligible optical distortion was confirmed on the digitizer plane and the image projected were fixed to ca. 17 fold. The lens also has reasonable performance as shown in Table 1, where several lenses examined were summarized. Furthermore, the projector was equipped with bright light source (150W) and was available at low price. Therefore, we concluded that the projector system was superior to the other for projecting fiber images.

Although we set the projector downward in this paper, the horizontal settlement is desirable for that if follwing apparatuses are avaiable: a translucent digitizer, as reported[6], on which the fiber images are dirctly projected, or a popular digitizer, such one as examined here, with a mirror system which is possible to project fiber images on the digitizer at a suitable magnification.

All of the instruments examined here were made in Japan and their performances were briefly summarized as follows: a slide projector (Color CabinIII; lamp 100V, 150W; Cabin Inc.), a close-up photographing stage (Macrophotographing table PMT-35; lamp 100V, 40W; Olympus Inc.), a digitizer (Mitablet DT-1000; effective area 380×260 cm^2; resolution 0.1 mm; Graph-tek Inc.), a microcomputer (NEC PC8001MKII; CPU 8-bit, μPD780), a monitor (NEC PC8050K; 12 inch CRT; 640×200 pixels), a disk unit (Epson TF-20; 5-inch, 2-drive), a printer (Epson RP80; 9×9 dot matrix for a character).

Fiber Length Digitizing System

A few different manners may be available for digitizing a fiber lenght in the system. Popular one is to count the numbers of crossing-points of the fiber images with gridlines set in a definite area, and is applied to morphometric cytology[10]. By means of this manner, a fiber length is obtainable as a mean of a sample lot, while a frequency distribution of the lengths is not directly derived. In order to obtain a frequency distribution of the length, we employed an alternative manner to digitize fiber images as mentioned in a following paragraph.

A fiber image on a digitizer was converted to a series of digital point-coordinates along the image by tracing it. The signals were transmitted to a 8-bit microcomputer as ASCII codes via RS232C cable. The coordinates digitized (X_i, Y_i) were processed to a length by an equation $\sum_i^n \sqrt{(X_i - X_{i-1})^2 + (Y_i - Y_{i-1})^2}$. This equation tells us that the image resolution depends on numbers of the digital coordinates converted on the digitizer.

In order to survey an optimal condition for the conversion rate, several rates were tested by means of tracing 10 cm of a line (repeated five times) on the digitizer. A series of coordinates thus digitized were shown as five dotted-lines in Figure 2. As expected, the numbers of converted points increased when the setting rate was increased. However, processings by a microcomputer (conversion of digital points to a length) took rather long time, if the many points were converted at the same time. In addition, this situation may bring inaccurate length, because, in addition to reading errors, it counts a lot of protruded points along an image traced.

In these contexts, well-balanced dottedlines were in the combination of 9600 baud rates/second for the transmission rate and 4–10 data/second with width mode (see foot-note of Figure 2) for the conversion rate. This combination showed that 14–28

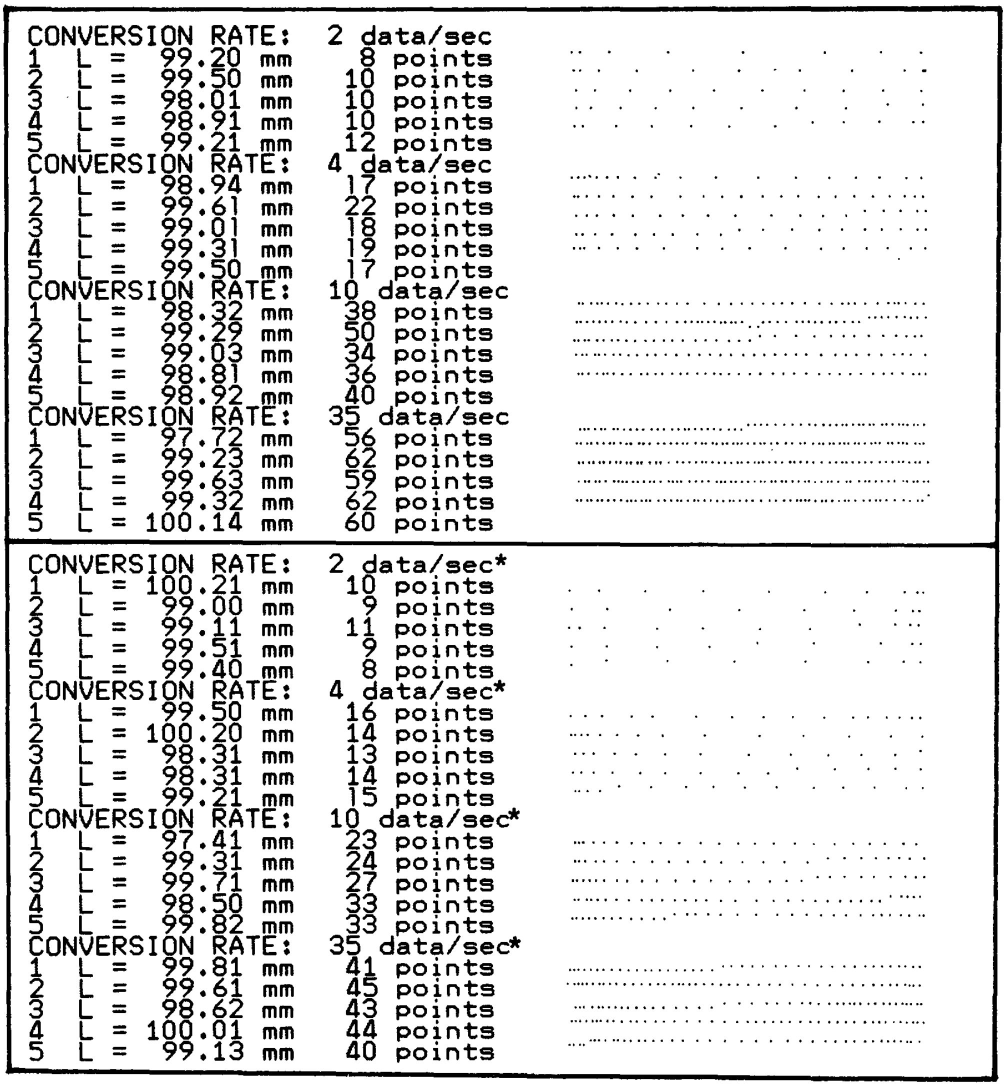

Fig. 2. Points read by a digitizer in the different conversion rates.
A line from left to right shows: tracing numbers (1-5), lengths found (L), digitized points per 10 cm, the digitized points printed. Details see in the text. * the conversion rates with width mode (the conversion starts only if the cursor moves more than 0. 1 mm on the digitizer).

dots/10 cm were digitized by the system. In other words, the data were processed at 0.2-0.4 mm intervals along a fiber on a sample specimen because magnification was 17 fold. The resolution is enough to trace strongly curved fiber images.

Respective lenghts were then modified to a real length according to the magnification fold. The lengths thus obtained were recorded both on the diskette and printer, with the date and time under working. An example is shown in Figure 3a. All of the processes mentioned above is controlled by a software presented in PROGRAM LIST 1.

The memorized data were then processed in order to obtain a mean, minimum

```
a  sample. name(magnification): 16a19( 17.05 )        83/09/13  14:52:28
    2.54 2.78 2.97 2.57 2.70 2.74 2.45 2.21 2.68 2.49 2.45 2.31 2.85 2.59 2.50 2.74
    2.46 2.39 2.69 2.46 2.73 2.86 2.66 2.31 2.97 2.27 2.94 2.38 2.43 2.56 2.54 2.21
    2.83 2.52 2.42 2.97 2.90 2.42 2.55 2.78 2.29 2.51 2.43 2.67 2.75 2.63 2.64 2.64
    2.62 2.77 2.81 3.15 2.99 2.38 2.34 2.96 2.68 2.70 2.82 2.41 2.37 2.81 2.76 2.60
    2.38 2.32 2.97 2.74 2.33 2.46 2.30 2.48 2.40 2.46 2.99 2.53 2.85 2.12 2.31 2.37
    2.38 2.36 2.69 2.39 2.52 2.57 3.04 2.31 2.43 2.51 2.70 2.61 2.51 2.47 2.17 2.30
    2.75 2.60 2.46 2.72

   sample name(magnification): 16a20( 17.05 )        83/09/13  15:09:55
    2.47 2.47 2.43 2.35 2.72 2.24 2.59 2.48 2.48 2.45 2.34 2.52 2.39 2.31 2.75 2.73
    2.75 2.38 2.41 2.86 2.14 2.44 2.63 2.45 2.34 2.08 2.40 2.79 2.90 2.58 2.58 3.01
    2.76 2.18 2.46 2.49 2.50 2.80 2.90 2.78 2.71 2.58 2.59 2.64 2.87 2.93 2.32 2.52
    2.80 2.53 2.38 2.37 2.36 2.87 2.75 2.79 2.82 2.76 2.71 2.88 2.95 2.62 2.77 2.63
    2.73 3.07 2.64 2.34 2.49 2.53 2.78 2.45 2.46 2.55 2.70 2.61 2.84 2.62 2.58 2.31
    2.94 2.73 2.82 2.39 2.39 2.60 2.41 2.72 2.83 2.53 2.78 2.48 2.47 2.66 2.94 2.64
    2.65 2.76 2.70 3.13
```

```
b  file name(magnification): 16a19(17.05)
    2.54 2.78 2.97 2.57 2.70 2.74 2.45 2.21 2.68 2.49 2.45 2.31 2.85 2.59 2.50 2.74
    2.46 2.39 2.69 2.46 2.73 2.86 2.66 2.31 2.97 2.27 2.94 2.38 2.43 2.56 2.54 2.21
    2.83 2.52 2.42 2.97 2.90 2.42 2.55 2.78 2.29 2.51 2.43 2.67 2.75 2.63 2.64 2.64
    2.62 2.77 2.81 3.15 2.99 2.38 2.34 2.96 2.68 2.70 2.82 2.41 2.37 2.81 2.76 2.60
    2.38 2.32 2.97 2.74 2.33 2.46 2.30 2.48 2.40 2.46 2.99 2.53 2.85 2.12 2.31 2.37
    2.38 2.36 2.69 2.39 2.52 2.57 3.04 2.31 2.43 2.51 2.70 2.61 2.51 2.47 2.17 2.30
    2.75 2.60 2.46 2.72
   frequency          : 0  0  0  0  0  0  0  24  46  28  2  0  0  0  0
   sample number      :100
   average length     :  2.5805
   minimum length     :  2.1216
   maximum length     :  3.1488
   variance           :  0.0498
   standard deviation:  0.2232

   file name(magnification): 16a20(17.05)
    2.47 2.47 2.43 2.35 2,72 2.24 2.59 2.48 2.48 2.45 2.34 2.52 2.39 2.31 2.75 2.73
    2.75 2.38 2.41 2.86 2.14 2.44 2.63 2.45 2.34 2.08 2.40 2.79 2.90 2.58 2.58 3.01
    2.76 2.18 2.46 2.49 2.50 2.80 2.90 2.78 2.71 2.58 2.59 2.64 2.87 2.93 2.32 2.52
    2.80 2.53 2.38 2.37 2.36 2.87 2.75 2.79 2.82 2.76 2.71 2.88 2.95 2.62 2.77 2.63
    2.73 3.07 2.64 2.34 2.49 2.53 2.78 2.45 2.46 2.55 2.70 2.61 2.84 2.62 2.58 2.31
    2.94 2.73 2.82 2.39 2.39 2.60 2.41 2.72 2.83 2.53 2.78 2.48 2.47 2.66 2.94 2.64
    2.65 2.76 2.70 3.13
   frequency          : 0  0  0  0  0  0  1  18  42  36  3  0  0  0  0
   sample number      :100
   average length     :  2.6073
   minimum length     :  2.0752
   maximum length     :  3.1312
   variance           :  0.0449
   standard deviation:  0.2119
```

Fig. 3. An example of the data printed out.
In the upper part (a), sample name, date, time, and the 100 of fiber lengths (unit: mm) measured are memorized on a sheet of printer paper. In addition to the sample name and lengths, their processed data are also printed in the lower part (b). Details see the text.

and maximum values, variance, standard deviation and frequency distribution of the respective populations. These statistical data were memorized on a diskette and printed as shown in Figure 3b. This process is controlled by a software presented in PROGRAM LIST 2.

The statistical values of fiber length above mentioned were automatically plotted against tree ages by PROGRAM LIST 3. The software also printed the frequency distribution at every annual rings in a three-dimensional manner. An

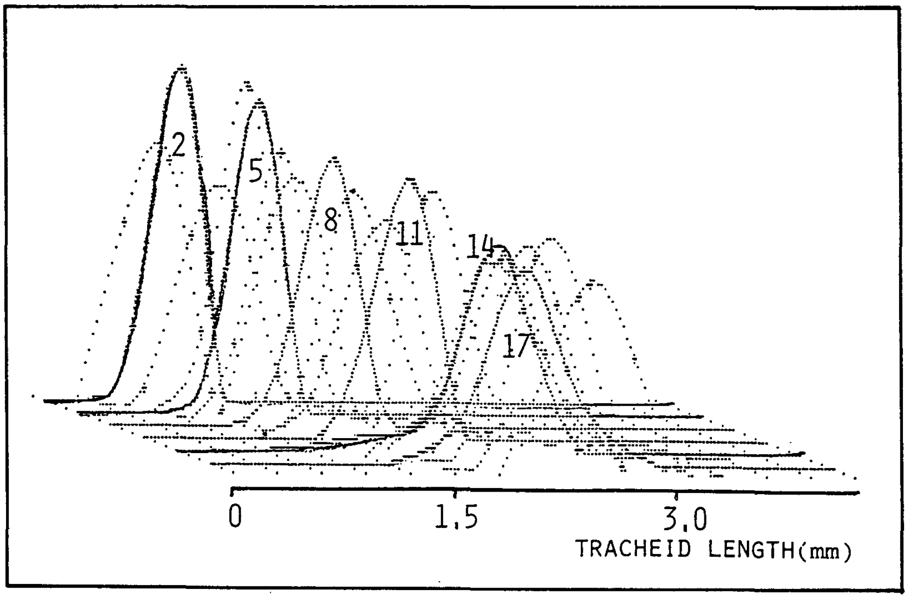

Fig. 4. Frequency distribution of fiber lengths against tree ages.
The frequency distribution of fiber (tracheid) lengths is drawn against a series of the annual rings as a three dimensional manner. The figures in the curves show the ring numbers. The distribution became wide from the pith to outer rings.

example of the graphics is shown in Figre 4.

Remarks in The Program Lists

N_{80} BASIC was used as the programing language[11], which is based on the BASIC of the Microsoft family. The programing aimed at the sentences that were as easy to understand as possible rather than high processing-speed.

PROGRAM LIST 1, named "filmsmemory", is developed for controlling digital conversion of the point-coordinates which located on the digitizer, for calculating a lenght from the coordinates, and for saving the lengths in a sample lot. Maximum sampling numbers are able to be set by changing a figure of L and S in the list numbers 120 and 290. In this case, it is 100 at maximum. The figure of MG in the list number 290 can be resetted according to the magnification of the projection image. When fiber images are necessary to be presented on a CRT, rem (') should be removed from the list numbers 420 and 425. The image-presentation, however, resulted in the slowdown of processing speed, and the operator had to wait for a while for counting a next fiber.

Concerning to RS-232C port in list numbers 520–660, a vector for the interruption is set in list number 530. The sentense in the list number enabes interruption and interrupts current registor. The port is intialized by the command "init% 1,-" in the number 540. Four cursor buttons on the digitizer are recognized by the flag F in the subroutine: cancellation of a fiber length after digital conversion (F=8), counting a next sample lot (F=4), memorization of a fiber length (F=2) etc.

PROGRAM LIST 2, named "filmsprint", is developed for summarizing fiber lengths in each sample lot as mensioned before. After running this program, the diskette, which memorized data files of the lengths by the PROGRAM LIST 1, have to insert in the drive number 2 of a disk unit. The summarized date will be memorized on the diskette in drive number 1. The numbers of sample lots (J) and anual rings (R) are set in the list number 70 and in the corresponding program sentences. Although they are J=150 and R=21 at maximum in this program, more larger-numbers may be set according to the memory size. When a series of sample lots, e.g. ring numbers of a tree, are partly discontinued, the list numbers 3060–3100 will be avaiable with changing file name.

PROGRAM LIST 3, named "filmsgraph", is develped for drawing graphs based on the data in the diskette which is memorized by PROGRAM LIST 2. The program consists of two parts. First one is able to plot the statistical data in the diskette against tree ages so that variation patterns of the fiber lenghs may be observed from pith to outer part of the xylem in a two dimensional presentation. The second subroutine is originated from the published one, which is adapted to our hardware system with modification[12]. Because the spline curves did not completely fit to the three dimensional plots, if-sentences were added to the subroutine in order to delete undesirable curve.

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PROGRAM LIST 1

```
10   '◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
20   '◆◆◆ Fiber Length Measuring System for    ◆◆◆
30   '◆◆◆ Employees: Digitizer+CPU+Disk Unit   ◆◆◆
40   '◆◆◆ file name:filmsmemory    1984.08.28  ◆◆◆
50   '◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
60       CMD CLS 3
70   PRINT "  CHECK PILOT LAMPS OF THE PRINTER AND "
80   PRINT "  DIGITIZER, THEN PRESS ***y*** KEY"
90       GOSUB 2230
100   CLEAR 1000:WIDTH 40,25:CONSOLE ,,0,:CMD SCREEN 1,0,3
110   DEFINT F,I,J,K,N,O,P,S,X,Y,W
120   DIM L(210),O(110),P(110),X(110),Y(110)
130  '◆◆◆◆◆◆◆key selection◆◆◆◆◆◆◆
140   DEFINT G,H
150      PRINT:PRINT
160  PRINT "***Select one of the heading numbers***"
170  PRINT "***(1-4) listed below if you want to***"
180  PRINT "  1. make a new or another file"
190  PRINT "  2. add further data in a file"
200  PRINT "  3. break operation"
210  PRINT "  4. delete a datum memorized"
220      PRINT:PRINT
230  PRINT " ■■■■ SAVE:1 ADD:2 END:3 DELETE:4 ■■■■"
240      PRINT:PRINT
250   INPUT "heading number";G:CMD CLS
260   IF G<1 OR G>4 THEN PRINT:GOTO 230
270   ON G GOTO 280,280,670,2000
280  '◆◆◆◆◆DATA save/add◆◆◆◆◆◆
290   MG=17.05:S=100
300   INPUT "sample name  ";NM$
310      PRINT:LPRINT
320  LPRINT "sample name(magnification): ";NM$;"(";MG;")  ";
330  LPRINT "    ";DATE$;"  ";TIME$
340   IF G=1 THEN OPEN "2:"+NM$ FOR OUTPUT AS #1:K=1
350   IF G=2 THEN GOSUB 1000:OPEN "2:"+NM$ FOR APPEND AS #1
360  CMD CLS 3:PRINT "READY!!":PRINT "file name:";NM$
370  FOR J=K TO S
380   GOSUB 520
390     F=0:PRINT%1,"S":BEEP 0
400          FOR I=1 TO N
410         L(I)=SQR((X(I)-X(I-1))^2+(Y(I)-Y(I-1))^2)+L(I-1):L(1)=0
420 '       O(I)=X(I)*.1682:P(I)=199-Y(I)*.0765
425 '       CMD PSET (O(I),P(I))
430          NEXT I
440      IF L(N)<.1 THEN J=J-1:I=1:NEXT J
450     L(N)=.1*L(N)/MG
460    LPRINT USING " #.##";L(N);
470    PRINT USING "###  L=####.###mm  ###";J;L(N);N
480   PRINT #1,L(N);",";:I=1
490  NEXT J
500   CLOSE:BEEP
505   PRINT%1,"Z":PRINT%1,"Z":PRINT%1,"Z":PRINT%1,"Z":PRINT%1,"Z"
510   CMD CLS 3:BEEP:GOTO 100
520  '◆◆◆◆◆length reading◆◆◆◆◆◆◆
530  POKE&H8001,&H23:POKE&H8000,&H7F
540  OUT &HE6,4:OUT &HE4,&HFF:INIT% 1,&HCA,&H37
550   IF F=8 THEN N=1:BEEP 1:CMD CLS 2:RETURN
560   IF F=4 THEN CLOSE:PRINT% 1,"S":CMD CLS3:GOTO 100
570   IF F=2 THEN N=I-1:BEEP 1:RETURN
580   IF F<2 AND I<2 THEN PRINT%1,"B"+"Wd"
590   IF F>1 OR I>1 THEN INPUT%1,X,Y,F:GOTO 520
600  FOR I=1 TO 100
610   INPUT%1,X,Y,F
620    IF F=1 THEN X(I)=X:Y(I)=Y ELSE 520
630    IF X(I)>3750 OR Y(I)>2550 THEN N=1:BEEP 1:RETURN
635    IF X(I)<50 OR Y(I)<50 THEN N=1:BEEP 1:RETURN
640   IF I=1 THEN BEEP1:BEEP1:BEEP0
```

```
650  NEXT I
660   J=J-1:N=1:BEEP:RETURN
670 '◆◆◆◆◆break operation◆◆◆◆◆◆◆
680 CMD CLS:LOCATE 1,4
690 PRINT "  ■■■■■DON'T TOUCH ANY KEY!!■■■■■"
700     PRINT
710 PRINT "   LEAVE MESSAGE TO THE INSTRUCTOR"
720 PRINT "   FOR BREAKING OPERATION"
730     PRINT:PRINT
740 PRINT "  when you want to reopen operation,"
750 PRINT "  input --cont-- from the key boad"
760 PRINT:PRINT:PRINT:PRINT
770    CLOSE:BEEP0:PRINT%1,"S":STOP:CMD CLS:GOTO 130
780 END
1000 '◆◆◆◆◆data addition◆◆◆◆◆◆◆
1010 OPEN "2:"+NM$ FOR INPUT AS #1
1020  K=1
1030 FOR J=1 TO S
1040   IF EOF(1) THEN 1090
1050    INPUT #1, L(J)
1060  K=K+1
1070   PRINT USING "### ##.###mm";J;L(J)
1080 NEXT J
1090  CLOSE:RETURN
2000 '◆◆◆◆◆data correction◆◆◆◆◆
2010 PRINT "SET A DATA-DISK ON DRIVE #2":PRINT
2020 INPUT "the sample number misoperated";W
2030 INPUT "sample name                  ";NM$
2040 OPEN "2:"+NM$ FOR INPUT AS #1
2050 FOR J=1 TO S
2060   IF EOF(1) THEN 2100
2070    INPUT #1, L(J)
2080   PRINT USING "### ##.###mm";J;L(J)
2090 NEXT J
2100  CLOSE:PRINT:PRINT
2110 PRINT " SURE ?  ==y)es or n)o=="
2120 PRINT "    sample name:";NM$
2130 PRINT "    no=";W;"  L=";L(W);"mm"
2140    GOSUB 2230
2150 OPEN "2:"+NM$ FOR OUTPUT AS #1
2160 FOR J=1 TO S
2170  IF J=W THEN NEXT J
2180   IF L(J)=0 THEN 2220
2190    PRINT#1,L(J);",";
2200   PRINT USING "### ##.###mm";J;L(J)
2210 NEXT J
2220  CLOSE:CMD CLS3:GOTO 130
2230 '◆◆◆◆◆stop subroutine◆◆◆◆◆◆◆
2240 IN$=INKEY$
2250 IF IN$="" THEN 2240
2260 IF IN$="y" THEN RETURN
2270 IF IN$="n" THEN 130
```

PROGRAM LIST 2

```
10   '◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
20   '◆◆◆ Fiber Length Measuring System :     ◆◆◆◆◆
30   '◆◆◆ Processed Data onto Printer & Disk◆◆◆◆◆
40   '◆◆◆ file name:filmsprint 1985.08.13     ◆◆◆◆◆
50   '◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
60   CLEAR 1000:WIDTH 40,25:CMD CLS 3:CONSOLE ,,0,:CMD SCREEN 1,0,3
70   DEFINT J,K,N,R:DIM FQ(50),L(210),R(100)
80    PRINT "Set Respective Diskettes on the Disk"
```

```
90   PRINT '    DRIVE#1:  Wright(Processed-Data)'
100  PRINT '    DRIVE#2:  Read(Found-Data)
110   PRINT
120  PRINT 'Turn on the Printer Switch'
130   PRINT:PRINT:PRINT
140 INPUT 'sample name (exp:33a)';A$
150 '◆◆◆◆◆data menu◆◆◆◆◆◆◆◆
160 FOR R=1 TO 21
170   B$=STR$(R)
180    IF R<10 THEN B$=RIGHT$(B$,1)
190     IF R>=10 THEN B$=RIGHT$(B$,2)
200    NM$=A$+B$
210   GOSUB 3000
220 NEXT R
230   BEEP:END
240 '◆◆◆◆◆◆line feed◆◆◆◆◆◆◆
250 FOR K=1 TO 16
260      LPRINT
270 NEXT K
280    RETURN
3000 '◆◆◆◆◆◆◆initialization◆◆◆◆◆◆
3010   LO=0:HI=0:TL=0:TV=0
3020     FOR K=1 TO 15
3030      FQ(K)=0
3040     NEXT K
3050   PRINT:PRINT:PRINT NM$
3060 'IF NM$='33a1' THEN 240
3080 'IF NM$='44a18' THEN 230
3090 'IF NM$=A$+'5' OR NM$=A$+'9' THEN LPRINT:LPRINT
3100 'IF NM$=A$+'13' OR NM$=A$+'17' THEN LPRINT:LPRINT
3110 '◆◆◆◆◆◆◆DATA load◆◆◆◆◆◆◆
3120 LPRINT:LPRINT 'file name(magnification): ';NM$;'(17.05)   '
3130 OPEN '2:'+NM$ FOR INPUT AS #1
3140 FOR J=1 TO 150
3150  IF EOF(1) THEN 3230
3160   INPUT #1, L(J)
3170    PRINT J;' ';L(J)
3180     IF J=1 THEN LO=L(1):HI=L(1)
3190    IF LO>L(J) AND L(J)>0 THEN LO=L(J)
3200   IF HI<L(J) THEN HI=L(J)
3210  TL=TL+L(J)
3220 NEXT J
3230  CLOSE:N=J-1:AV=TL/N:PRINT
3240 PRINT USING 'sample numbers: ###';N
3250 PRINT USING 'average length: ###.###mm';AV
3260 PRINT USING 'minimum length: ###.###mm';LO
3270 PRINT USING 'maximum length: ###.###mm';HI
3280 PRINT:PRINT '   [redacted]UNDER PROCESSING[redacted]'
3290 '◆◆◆◆◆◆◆ frequency◆◆◆◆◆◆◆◆◆◆◆
3300  MAX=FQ(1)
3310  LL=CINT(LO/.3)+1:LH=CINT(HI/.3)+1
3320 FOR J=1 TO N
3330   FOR K=LL TO LH
3340    IF L(J)>=(.3*K-.3) AND L(J)<.3*K THEN FQ(K)=FQ(K)+1
3350    IF MAX<FQ(K) THEN MAX=FQ(K)
3360   NEXT K
3370 NEXT J
3380 '◆◆◆◆◆◆◆◆data summary◆◆◆◆◆◆◆◆◆◆◆◆
3390 CMD CLS 3
3400 PRINT 'sample name';NM$
3410 PRINT 'frequency:'
3420   FOR K=1 TO LH
3430     PRINT FQ(K);
3440   NEXT K
3450 FOR J=1 TO N
3460   TV=TV+(L(J)-AV)^2
3470 NEXT J
3480 VR=TV/(N-1)
3490 SD=SQR(VR)
```

```
3500       PRINT
3510 PRINT USING "sample number      :###";N
3520 PRINT USING "average length     :###.####";AV
3530 PRINT USING "minimum length     :###.####";LO
3540 PRINT USING "maximum length     :###.####";HI
3550 PRINT USING "variance           :###.####";VR
3560 PRINT USING "standard deviation:###.####";SD
3570 '◆◆◆◆◆DATA PRINT(printer & disk)◆◆◆
3580 FOR J=1 TO N
3590  LPRINT USING " #.##";L(J);
3600 NEXT J:LPRINT
3610  LPRINT "frequency          :";
3620 OPEN "1:sam"+NM$ FOR OUTPUT AS #1
3630 PRINT #1,N;",";AV;",";LO;",";HI;",";VR;",";SD;",";
3640 FOR K=1 TO LH
3650  LPRINT FQ(K);
3660  PRINT #1,FQ(K);",";
3670 NEXT K
3680  CLOSE:LPRINT
3690 LPRINT USING "sample number      :###";N
3700 LPRINT USING "average length     :###.####";AV
3710 LPRINT USING "minimum length     :###.####";LO
3720 LPRINT USING "maximum length     :###.####";HI
3730 LPRINT USING "variance           :###.####";VR
3740 LPRINT USING "standard deviation:###.####";SD
3750   RETURN
```

PROGRAM LIST 3

```
10   '◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
20   '◆◆◆ Fiber Length Measuring System for ◆◆◆◆◆
40   '◆◆◆ file name:filmsgraph 1984.09.08   ◆◆◆◆◆
50   '◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆◆
60   CLEAR 1000:WIDTH 40,25:CMD CLS 3:CONSOLE ,,0,:CMD SCREEN 1,0,3
70   DEFINT J,K,N,R:DIM FQ(20),F(30),R(30)
80    PRINT "Set a Diskette on the Disk Drive #2"
90    PRINT "for reading the results summarized"
100    PRINT
110   PRINT "Turn on the Printer Switch"
120    PRINT:PRINT:PRINT
130  INPUT "sample name (exp:33a)";A$
140  '◆◆◆◆◆data menu◆◆◆◆◆◆◆◆
150  FOR R=1 TO 21
160    B$=STR$(R)
170     IF R<10 THEN B$=RIGHT$(B$,1)
180      IF R>9  THEN B$=RIGHT$(B$,2)
190     NM$="sam"+A$+B$
200    GOSUB 230
210  NEXT R
220    BEEP:END
230  '◆◆◆◆◆◆◆initialization◆◆◆◆◆◆
240    LO=0:HI=0:TL=0:TV=0
250      FOR K=1 TO 15
260       FQ(K)=0
270      NEXT K
280    PRINT:PRINT:PRINT NM$
290  'IF NM$="sam33a1"  THEN RETURN
300  'IF NM$="sam44b5"  THEN RETURN
310  'IF NM$="sam44a18"  THEN 640
311  'IF NM$="sam33b13"  THEN 640
312  'IF NM$="sam44b9"  THEN 640
313  'IF NM$="sam45b13"  THEN 640
314  'IF NM$="sam51b11"  THEN 640
315  'IF NM$="sam29b11"  THEN 640
316  'IF NM$="sam16b12"  THEN 640
```

```
317 'IF NM$='sam33c10' THEN 640
318 'IF NM$='sam44c6' THEN 640
319 'IF NM$='sam45c9' THEN 640
320 'IF NM$='sam51c8' THEN 640
321 'IF NM$='sam29c10' THEN 640
322 'IF NM$='sam16c8' THEN 640
325 '◆◆◆◆◆◆◆DATA load◆◆◆◆◆◆◆
330  OPEN '2:'+NM$ FOR INPUT AS #1
340  FOR K=1 TO 24
350   IF EOF(1) THEN 400
360   INPUT #1,F(K)
370   IF K=6 THEN GOSUB 410
380   IF K>6 THEN PRINT F(K);
390  NEXT K
400       CLOSE:GOTO 500
410 '◆◆◆◆◆
420 PRINT USING 'sample number     :###';F(1)
430 PRINT USING 'average length    :###.####';F(2)
440 PRINT USING 'minimum length    :###.####';F(3)
450 PRINT USING 'maximum length    :###.####';F(4)
460 PRINT USING 'variance          :###.####';F(5)
470 PRINT USING 'standard deviation:###.####';F(6)
480 PRINT 'frequency:'
490   RETURN
500 '◆◆◆◆◆
510 N=F(1):AV=F(2):LO=F(3):HI=F(4):VR=F(5):SD=F(6)
520 '◆◆◆◆◆
530 X1=24+14*(R-1):X2=344+14*(R-1)
540  CMD CIRCLE (X1,176-AV*40),2
550  CMD CIRCLE (X1,176-LO*40),1
560  CMD CIRCLE (X1,176-HI*40),1
570  CMD CIRCLE (X1,176-AV*40+SD*40),1
580  CMD CIRCLE (X1,176-AV*40-SD*40),1
590  CMD CIRCLE (X2,176-VR*4000/3),2
600  CMD LINE (X1,176-AV*40+SD*40)-(X1,176-AV*40-SD*40)
610   IF R=21 THEN 640
620 TL=0:TV=0
630 RETURN
640 '◆◆◆◆◆unit marks◆◆◆◆◆◆◆
650  CMD LINE (10,176)-(310,16),,B
660  CMD LINE (330,176)-(630,16),,B
670   X1=0:X2=0:Y1=0:Y2=0
680 FOR R=1 TO 21
690   X1=24+14*(R-1):X2=344+14*(R-1)
700   Y1=176-20*R:Y2=(176-R*40/3)
710  IF X1<310 THEN CMD LINE (X1,16)-(X1,18)
720  IF X1<310 THEN CMD LINE (X1,174)-(X1,176)
730  IF X2<630 THEN CMD LINE (X2,16)-(X2,18)
740  IF X2<630 THEN CMD LINE (X2,174)-(X2,176)
750  CMD LINE (10,Y1)-(12,Y1)
760  CMD LINE (308,Y1)-(310,Y1)
770  IF Y2>16 THEN CMD LINE (330,Y2)-(332,Y2)
780  IF Y2>16 THEN CMD LINE (628,Y2)-(630,Y2)
790 NEXT R
800      CMD COPY2:BEEP
1000 '◆◆◆◆◆◆◆three dimensional display◆◆◆◆◆◆◆
1010 CLEAR 1000:DEFINT K,X,Y,R
1020 CMD CLS 3:CONSOLE ,,0,:CMD SCREEN 1,0,3
1030 DIM FQ(25),B(15),C(15),D(15),R(30),X(15),Y(15)
1040 INPUT 'sample name (exp:33a)';A$
1050 '◆◆◆◆◆file name◆◆◆◆◆◆◆
1060 FOR R=1 TO 19
1070   B$=STR$(R)
1080    IF R<10 THEN B$=RIGHT$(B$,1)
1090     IF R>9  THEN B$=RIGHT$(B$,2)
1100    NM$='sam'+A$+B$
1110   GOSUB 1140
1120  NEXT R
1130    CMD COPY2:BEEP:END
```

```
1140 '◆◆◆◆◆read data◆◆◆◆◆◆◆
1150    FOR K=1 TO 15
1160     FQ(K)=0
1170    NEXT K
1180  PRINT:PRINT:PRINT NM$
1190 'IF NM$="sam33a1" THEN RETURN
1200 'IF NM$="sam44b5" THEN RETURN
1210 'IF NM$="sam44a18" THEN 1130
1211 'IF NM$="sam33b13" THEN 1130
1212 'IF NM$="sam44b9" THEN 1130
1213 'IF NM$="sam45b13" THEN 1130
1214 'IF NM$="sam51b11" THEN 1130
1215 'IF NM$="sam29b11" THEN 1130
1216 'IF NM$="sam16b12" THEN 1130
1217 'IF NM$="sam33c10" THEN 1130
1218 'IF NM$="sam44c6" THEN 1130
1219 'IF NM$="sam45c9" THEN 1130
1220 'IF NM$="sam51c8" THEN 1130
1221 'IF NM$="sam29c10" THEN 1130
1222 'IF NM$="sam16c8" THEN 1130
1225 '◆◆◆◆◆◆◆DATA load◆◆◆◆◆◆◆
1230  OPEN "2:"+NM$ FOR INPUT AS #1
1240 FOR K=1 TO 21
1250  IF EOF(1) THEN 1280
1260   INPUT #1,FQ(K)
1270 NEXT K
1280      CLOSE
1290 FOR K=7 TO 21
1300   FQ(K-6)=FQ(K)
1310   PRINT FQ(K)
1320 NEXT K
1330 '◆◆◆◆◆◆graphic pattern◆◆◆◆
1340 PRINT
1350 FOR K=1 TO 15
1360   X(K)=36+24*(K-1)+6*(R-1)
1370   Y(K)=104-FQ(K)+R-1
1380  IF Y(K)<104+R-1 THEN CMD CIRCLE (X(K),Y(K)),1
1390  IF Y(K)=104+R-1 THEN CMD PSET (X(K),Y(K))
1400 NEXT K
1410 '◆◆◆◆◆◆◆spline coefficient◆◆◆◆◆◆◆◆◆
1420 D(1)=X(2)-X(1)
1430 C(2)=(Y(2)-Y(1))/D(1)
1440 FOR K=2 TO 14
1450  D(K)=X(K+1)-X(K)
1460   B(K)=2*(D(K-1)+D(K))
1470    C(K+1)=(Y(K+1)-Y(K))/D(K)
1480   C(K)=C(K+1)-C(K)
1490  IF FQ(K)=0 AND FQ(K+1)=0 THEN C(K)=0
1500 NEXT K
1510 B(1)=-D(1):B(15)=-D(14):C(1)=0:C(15)=0
1520 C(1)=C(3)/(X(4)-X(2))-C(2)/(X(3)-X(1))
1530 C(15)=C(14)/(X(15)-X(13))-C(13)/(X(14)-X(12))
1540 C(1)=C(1)*D(1)*D(1)/(X(4)-X(1))
1550 C(15)=-C(15)*D(14)*D(14)/(X(15)-X(12))
1560 FOR K=2 TO 15
1570  T=D(K-1)/B(K-1)
1580   B(K)=B(K)-T*D(K-1)
1590    C(K)=C(K)-T*C(K-1)
1600  IF FQ(K)=0 AND FQ(K-1)=0 THEN C(K)=0
1610 NEXT K
1620 C(15)=C(15)/B(15)
1630 FOR IB=1 TO 14
1640  K=15-IB
1650   C(K)=(C(K)-D(K)*C(K+1))/B(K)
1660  IF FQ(K)=0 AND FQ(K+1)=0 THEN C(K)=0
1670 NEXT IB
1680 B(15)=(Y(15)-Y(14))/D(14)+D(14)*(C(14)+2*C(15))
1690 FOR K=1 TO 14
1700   B(K)=(Y(K+1)-Y(K))/D(K)-D(K)*(C(K+1)+2*C(K))
```

```
1710   D(K)=(C(K+1)-C(K))/D(K)
1720   C(K)=3*C(K)
1730  IF FQ(K)=0 AND FQ(K+1)=0 THEN B(K)=0:C(K)=0:D(K)=0
1740 NEXT K
1750 C(15)=3*C(15):D(15)=D(14)
1760 '◆◆◆◆◆drawing graph◆◆◆◆◆◆◆
1770 FOR K=1 TO 14
1780   PRINT Y
1790  FOR X=X(K) TO X(K+1) STEP 2
1800   Y=Y(K)+B(K)*(X-X(K))+C(K)*(X-X(K))^2+D(K)*(X-X(K))^3
1810    IF R=2 OR R=5 OR R=8 THEN GOSUB 1880:GOTO 1850
1815    IF R=11 OR R=14 OR R=17 THEN GOSUB 1880:GOTO 1850
1820    IF Y>103+R THEN NEXT X:GOTO 1860
1830    IF Y(K)=103+R AND Y(K+1)=103+R THEN 1860
1840     CMD PSET (X,Y)
1850  NEXT X
1860 NEXT K
1870 RETURN
1880 '◆◆◆◆◆
1890 IF X=X(1) THEN 1920
1900 IF Y>103+R THEN Y=103+R
1910 IF Y1<103+R THEN CMD LINE (X1,Y1)-(X,Y)
1915 IF Y<103+R THEN CMD LINE (X1,Y1)-(X,Y) ELSE CMD PSET (X1,Y1)
1920 X1=X:Y1=Y
1930 RETURN
```

After the present paper was accepted, bags on the basic system concerning with the numerical calculations of square root were pointed (Interface No. 105, 280-289, 1986; in Japanese). The variance as shown in Fig. 4 will be increased by the bag (in addition to the reading errors derived from the digitizer) when the digital conversions are repeated. Therefore, the net (or naturally occured) distribution in Fig. 4 should be carefully examined (see also ref 2).