A system for processing by digital computer spirograms acquired in field surveys

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Derrett, C. J. and Brown, C. (1975). *Thorax*, **30**, 674–677. **A system for processing by digital computer spirograms acquired in field surveys.** Instrumentation and techniques are described for recording expiratory spirograms in the field and analysing them with a digital computer in the laboratory. A commercially available spirometer is modified to give an oscillating electrical output signal which is recorded on a cassette tape recorder. The computer displays the spirogram, calculates the forced vital capacity, one-second forced expiratory volume, maximum mid-expiratory flow, and time to expire 25%, 50%, 75%, and 90% of the vital capacity.

Investigations into the rôle of environmental or occupational factors in the development of chronic respiratory disease often require simple measurements of ventilatory capacity to be made among large, widely dispersed populations. The forced expiratory volume test is widely used in this context.

Instruments are already available that provide immediate read-out of peak flow (PF) (Wright and McKerrow, 1959), forced expiratory volume (FEV) and forced vital capacity (FVC) (McDermott, McDermott, and Collins, 1968; Beumer and Hardork, 1970; Klose, 1972; Fitzgerald, Smith, and Gaensler, 1973), but recently much attention has been paid to other more complex spirographic measures such as the maximal mid-expiratory flow (MMEF) and the time required to expire the middle half of the forced vital capacity ($FVC_{t(0.25-0.75)}$) (Allen and Sabin, 1971). These are measures of the middle part of the spirogram, which are thought to be largely independent of effort. They are considered by some workers to be of importance in studies of changes in the small airways (McFadden and Linden, 1972; Macklem, 1972). Unfortunately, they are not readily measured by simple automatic computation because the whole spirogram must be recorded before it can be analysed.

In the system described here the spirogram is recorded on magnetic tape, using inexpensive, commercially available equipment, and analysed using a laboratory digital computer.

THE SPIROMETER AND VARIABLE FREQUENCY OSCILLATOR

The spirometer we chose was the portable bellows apparatus described by McDermott *et al.* (1968), an instrument which had proved suitable for field surveys. The basic commercially available instrument (Gawr Electronics Inst. Ltd) is modified by mounting the volume indicator dial on the spindle of a low inertia potentiometer (R_4) which controls the frequency of a simple relaxation oscillator (Fig. 1).
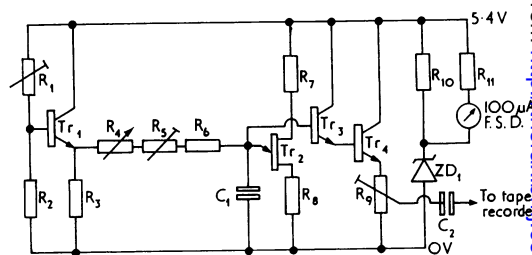

FIG. 1. *Circuit diagram of variable frequency oscillator. The output frequency is controlled by a potentiometer (R_4) linked mechanically with the spirometer bellows.*

R_1 = 5K Ohms (preset)
R_2 = 22K Ohms
R_3 = 6·8 Ohms
R_4 = 40K Ohms (low inertia potentiometer)
R_5 = 10K Ohms (10 turn preset)
R_6 = 10K Ohms
R_7 = 2·2K Ohms
R_8 = 47 Ohms
R_9 = 1K Ohms (preset)
R_{10} = 820 Ohms
R_{11} = 12K Ohms
C_1 = 0·01 μF
C_2 = 0·1 μF
ZD_1 = C4V3 (4·3 volt zener diode)
Tr_1, Tr_3, Tr_4 = BC109
Tr_2 = 2N2646

A bipolar transistor (Tr₁) provides a constant voltage supply which charges a capacitor (C₁) via a resistor chain (R₄, R₅, and R₆). When the potential on the capacitor reaches a level to bias the emitter of the unijunction transistor (Tr₂) positively, the latter turns on and the capacitor discharges. The output signal has a ramp wave-form with a period of oscillation linearly proportional to the volume dial setting. We have found the system is convenient if the frequency is set at 5000 Hz for 0 litres on the dial and 2500 Hz for 5 litres. The oscillator's frequency/volume characteristic is stable in use. Regular checking of the calibration, other than that recommended by the manufacturer of the instrument, is not necessary.

THE TAPE RECORDER

The oscillator circuit is matched to the input of a portable cassette tape recorder (National Panasonic Model RQ-212DS) by an additional pair of transistors (Tr₃ and Tr₄) in a conventional emitter follower circuit. The tape recorder is mounted on the side of the spirometer together with the oscillator, a battery level indicator, and three push-button control switches (Fig. 2).

The quality of the recording cassettes greatly influences the performance of the instrument. Cassettes of professional quality tape with a playing

FIG. 2. *The modified spirometer showing the cassette tape recorder and controls. The potentiometer (R₄) is mounted behind the dial.*

time of 30 minutes per side (Mallory Duratape EFR 60) are satisfactory.

THE COMPUTER AND ITS INTERFACE

The tapes are analysed using a laboratory digital computer system (Hewlett Packard 2116B). The cassette is replayed with a mains-operated tape deck (Crown CDM-11), and the frequency of the signal is converted to a series of binary numbers which are input to the computer. The frequency-digital converter and interface (Fig. 3) are made from standard electronic logic (5 volt TTL).

The replayed spirometer wave form is first converted to square wave pulses and then fed to a counter (0-127). The number of pulses counted in a period of 20 ms is stored by a binary latch circuit and the stored number is presented at the input of the computer. A push-button switch is also wired to one of the computer input lines to enable the operator to control the program manually. Fifteen microseconds after storing the count, the counter is reset to zero. While the next 20 ms count is taking place the computer is signalled that data are ready for input. They are read under control of the computer program.

OPERATING PROCEDURE   Before the start of each test, a verbal announcement of the subject's name and serial number is recorded, using the microphone built into the tape recorder. The operator then switches on the oscillator and for approximately 5 seconds the 0 litre signal (5000 Hz) is recorded. After this has been done, the subject performs a forced expiration in the usual way. At the end of the test, or series of tests, the recorder is stopped and the tape cassette is removed for analysis.

During the analysis the tape is replayed at normal speed. The operator listens to the subject identification announcement and types the relevant information on a keyboard. When the oscillator reference signal is heard, he presses the interface push-button and the reference frequency is computed. Operation of the system is then completely automatic. The computer distinguishes the beginning and end of each spirogram and stores the data until the operator presses the button again. Then he can select whether he wishes to display the spirogram graphically (singly or superimposed on others) (Fig. 4), compute the spirogram parameters, print the results, punch the data on paper tape, or move on to a new subject.

COMPUTER PROGRAM   The computer program (written in FORTRAN IV) comprises a main program handling data display, printing, and punching together with sub-routines for reading the tape
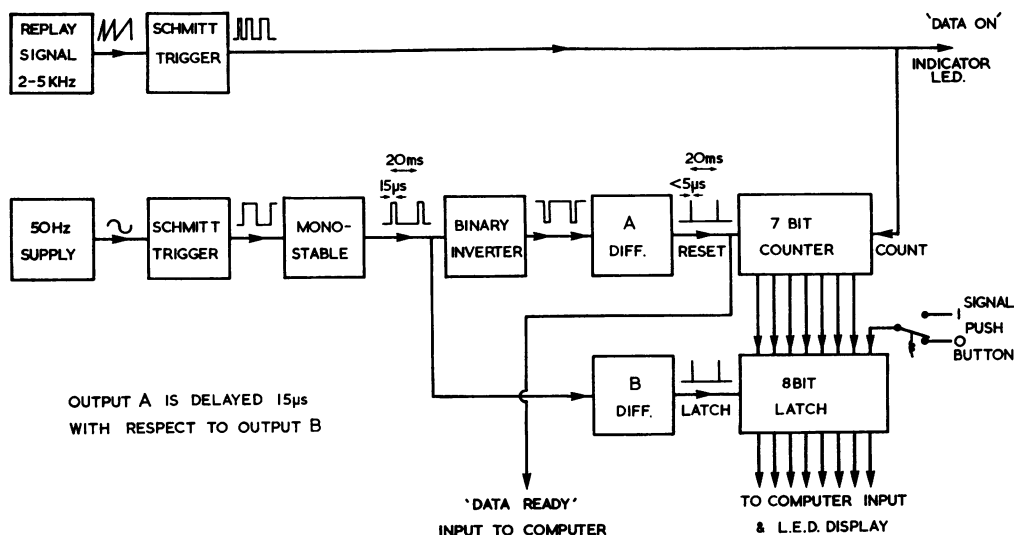
FIG. 3. *Schematic diagram of frequency-digital converter and computer interface.*
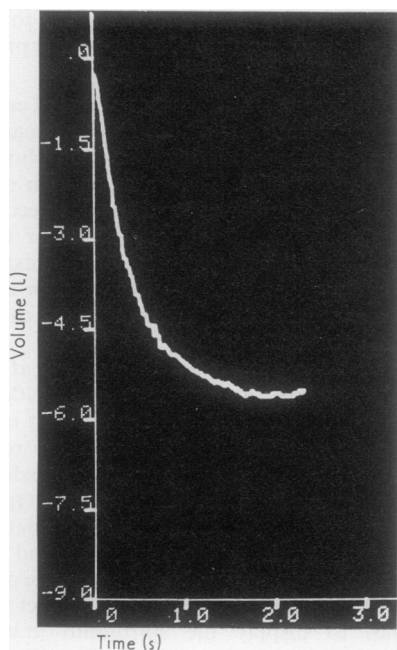

FIG. 4. *A typical forced expiratory spirogram photographed from the computer's visual display unit.*

player interface, sampling several sequential spirograms, and computing the spirogram parameters, $FEV_{1.0}$, FVC, MMEF, $FVC_{t(0-0.25)}$, $FVC_{t(0-0.5)}$, $FVC_{t(0-0.75)}$, and $FVC_{t(0-0.9)}$.

The 5000 Hz reference frequency is checked by the computer during replay; a correction factor is calculated and is used to compensate for any differences between the recording and the replay speed.

The computer algorithms detecting the start and finish of forced expirations have been designed to tolerate noise and tape 'drop outs' (imperfections in the tape recording surface). The start of expiration is recognized when the expired volume exceeds 0·15 litres and the end is recognized when the expired volume has remained constant for a period of at least 800 ms.

The count is inversely proportional to the expired volume and so a change of one in the count represents a larger change in volume at high volumes than at the start of expiration. To improve the resolution at high volumes the cumulative count from a number of 20 ms periods is used.

SOURCES OF ERROR

The main sources of error in this technique are as follows:

1. Non-linearity in the dial potentiometer ($\pm 0·5\%$).
2. Quantization errors of the frequency to digital converter. These increase with volume. They are reduced by digital filtering to less than $\pm 0·05$ litres.
3. Wow and flutter on record and replay ($< \pm 1\%$).
4. Tape stretch and tape 'drop outs'. These may cause large errors but can be avoided if good quality tape cassettes are used and if straining of the tape during rewind is avoided.
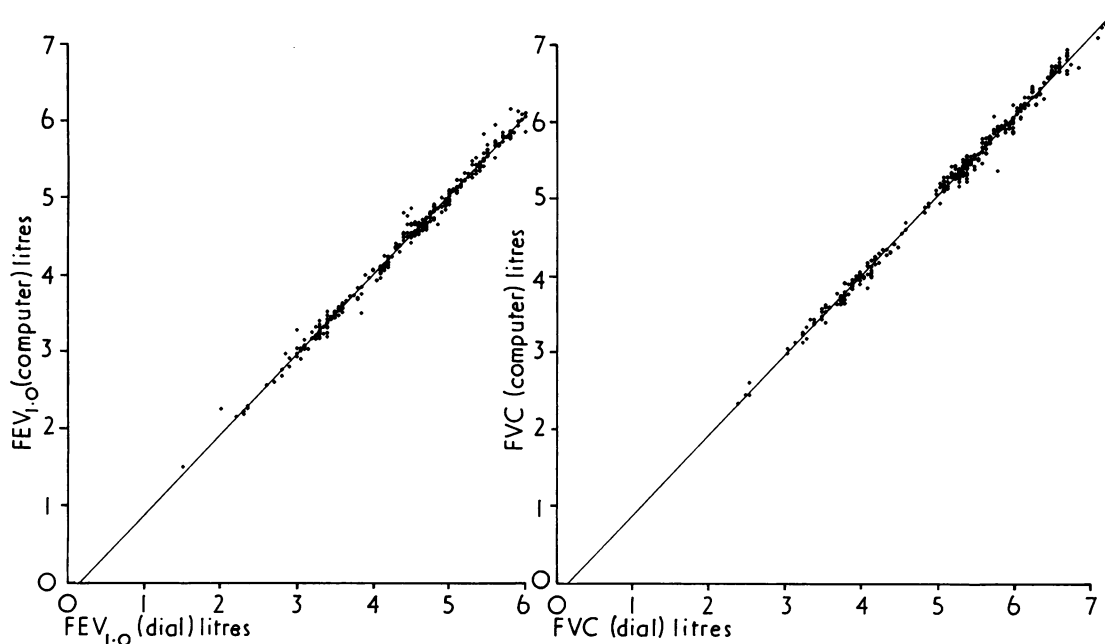5. Inaccuracies in the mechanical part of the

FIG. 5. *Comparison of computer-calculated and operator-observed values for* FEV$_{1.0}$ *and* FVC.

McDermott spirometer. The linearity of this should be $\pm 1\%$ of full-scale reading.

EVALUATION

The automated part of the system was evaluated using data obtained from a group of 62 medical students. Each subject was asked to perform five forced expirations. The spirograms were recorded on the tape recorder and the values of FEV$_{1.0}$ and FVC were noted from the spirometer dial. The tape recordings were analysed using the system described. The mean of the five values of FEV$_{1.0}$ and FVC calculated by the computer (FEV$'_{1.0}$ and FVC$'$) were compared with those observed by the operator (FEV$''_{1.0}$ and FVC$''$) (Fig 5). For the individual values the correlation coefficients were 0·996 and 0·997 respectively. The regression equations were:

FEV$'_{1.0}$ = 1·04 $\times$ FEV$''_{1.0}$ $-$ 0·14 (litres)
FVC$'$ = 1·04 $\times$ FVC$''$ $-$ 0·15 (litres)

We believe that the technique is sufficiently accurate and consistent to be of value for both survey and clinical use. Although the digital analyser is costly, only one is needed for processing data collected with a number of spirometers.

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