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SMALL COMPUTER ASSISTED ANALYSIS OF CAMERA RENOGRAMS

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INTRODUCTION

Many clinical advantages arise from the use of a small dedicated computer system interfaced with a scintillation camera. For example, the computer can be programmed for the repetitive execution of complex protocols, and scintiscans can be stored and retrieved from magnetic tape or disc. This is particularly useful in storing information during dynamic studies for analysis. While each of these uses is important, an area of increasing significance is the use of the computer to assist in analyses of patient studies, analyses that require lengthy mathematical handling as in the renogram program discussed below.

The presence of a digital computer located in a clinical facility avoids many of the problems associated with using a large computer at some remote location. There is no transporting and transposing of data and often the analysis of a study can be completed shortly after acquisition of the data. In addition, conversational language for small machines can be used with a minimum of training by the clinical personnel and program changes can be rapidly implemented and tested.

The disadvantages of small computers are well known. For example, they usually have a small memory capacity and are slower than large computers. These features impose some restrictions on the complexity of problems that can be easily programmed.

In this article the usefulness and convenience of a small computer-anger camera system is demonstrated by means of a renal function analysis program written for this system. The program is based on CABBS, Computer-Assisted Blood Background Subtraction, written by Britton & Brown and programmed for a CDC-6600, a large computer system (1) for data acquired with 3 probes. This type of renal function analysis is an example of the many programs that may be utilized by departments that do not have access to a large computer. The following discussion is devoted to the Small Computer-Assisted Analysis of Renograms (SCAAR) starting with comments on blood background subtraction.

BLOOD BACKGROUND SUBTRACTION

Use of blood background subtraction is an important advantage of this program because it can improve diagnostic accuracy, particularly in the case of a poorly-functioning kidney. For instance, we anticipate that cases of poor renal function due to obstruction can be separated from cases of parenchymal disease causing poor renal function with no obstruction. This differentiation is difficult to make without blood background subtraction. Progressively, the scintillation camera has become the instrument of choice for renography, but background subtraction has only occasionally (6) been applied. However, the choice of a suitable area for the determination of

background is limited, with the camera face being small in comparison with the area of the two kidneys and their outflow system. In the past, blood background subtraction was usually done using a system of three probes; one over the left subclavicular region (blood background) and one over each kidney, in conjunction with an analog or digital computer. The left subclavicular region has been "validated" as a choice for the background area by its close similarity with that actually found over a nephrectomy site (1, 3, 4, 5).

The present system has the following additional advantages: visualization of anatomical variations, precise patient positioning for the small camera face, and the derivation of a numerical estimate of "true" individual renal function.

When renography is being repeatedly performed on the same patient, important but small changes in renal function may be easier to detect after blood background subtraction; for instance in the evaluation of function of a newly transplanted kidney.

A scintillation camera with a computer has been used to determine the ratio of blood background over each of the two kidneys to a non-renal region. The patient is given 1.0 mCi ^{99m}Tc-labeled human serum albumin prior to the renogram (Fig. 1). Generally, a scintiphoto of 50,000 counts is acquired. Using the computer, regions are designated ("flagged") and the counts in each region totalized. Thus the ratio of background region counts to the right kidney and the nearly always different ratio of background region to the left kidney can be obtained. During the analysis of the renogram, an activity-time curve is generated for each of the three regions. With the background ratio the "background" component from each of the kidneys can be calculated. Possible choices for background areas are as follows:

1. An area including the upper aorta
2. An area including part of the spleen
3. As a "halo" about each kidney
4. Below the kidney, but lateral to the aorta and ureters.

At present we are not sure which area best represents the renal background.

SMALL COMPUTER ASSISTED ANALYSIS OF RENOGRAMS (SCAAR)

From the many methods of renal function analysis which have been published, the method used and improved over the last 10 years by Britton and Brown (1) was chosen for adaptation to a small computer. In particular, it is hoped that the blood background subtraction and separation of uptake and removal components of the renogram could add new information in a continuing study by Atkins et al (7) on ^{99m}Tc DTPA and a comparison study of renograms using ^{99m}Tc-DTPA and ^{131}I-Hippuran. SCAAR was written for the ND-812 Central Processor of a Med II System* which had been interfaced to an Anger Camera. From the 16K memory (12 bit word length) over 8K are used for image storage (two 64 x 64 frames). A large portion of the remaining 8K is devoted to a conversational language interpreter. The remainder of the memory is available for user-written programs which are stored on the disc ("text buffers"). SCAAR uses two text buffers. The second text buffer is called by the program and overlays the first text buffer.

The curves are generated from the total counts in designated "flagged" areas (right kidney, left kidney and background) in the serial scintiphotos stored on the disc. After injection of ^{99m}Tc-DTPA or ^{131}I-Hippuran, the scintiphotos are acquired every 15 seconds for a total period

*Nuclear Data Corp., Chicago

of 15 minutes, or more if clinically indicated. A typical ^{99m}Tc-DTPA scintiphoto is shown in Figure 2 with "flagged" right and left kidneys and two background regions. The steps in the analysis are listed in Table 1 and are discussed below.

SCAAR is based primarily on a relationship between the activity time curve of the blood "background" and the accumulated concentration of isotope in the functioning kidney. This expression can be determined from a two-compartment model of the blood-kidney system which is assumed to be valid between 45 seconds and 2 minutes 45 seconds after injection of the isotope, i.e. before any of the radioactivity leaves the kidney (1)It is stated as follows:

$$\frac{d\,(S_k \quad X_k \quad (t)\,)}{dt} = \rho_{bk} \quad X_b \quad (t) - \quad \rho_{kb} \quad X_k \quad (t) \qquad 1.$$

where S_k = functional kidney (in units of mass).

X = the fractional amount of material which is radioactive. The specific activity of the blood, X_b, or kidney, X_k.

ρ = transfer rate (units of mass per unit time) from blood to kidney (bk) and kidney to blood (kb).

During the first half minute the bolus of isotope is distributed throughout the vascular bed. For approximately the next 2 minutes the kidney continues to accumulate the injected material, but usually none of the isotope is eliminated by the passage of urine to the bladder.

If the transfer rate from the kidney to the blood, ρ_{kb}, is negligible (this assumption may not be true in certain types of renal impairment) equation (1) becomes

$$\frac{d\,(S_k \quad X_k \quad (t) \quad)}{dt} = \rho_{bk} \quad X_b \quad (t) \qquad 2.$$

Assuming ρ_{bk} is unaffected by the concentration of activity in the functional kidney, then by integration:

$$S_k \quad X_k \quad (t) = \rho_{bk} \int_o^t \quad X_b \quad (\tau) \quad d\tau \qquad 3.$$

where $X_k \quad (t) = o$ at $t = o$

τ is the running value of time.

In other words, at a time t the accumulated total of activity in either kidney is proportional to the accumulated total of blood background activity. Usually the constant of proportionality is different for right and left kidneys.

From the serial scintiphotos, counts from the kidney area and the appropriate background regions are determined, and equation 3 is rewritten in terms of measured quantities.

$$Q_k \quad (t) = m \int_o^t \quad Q_b \quad (\tau) \quad d\tau + \quad c \qquad 4.$$

Where Q_k is the measured kidney count and Q_b is the count from the background region. Furthermore, m is the "uptake constant" and c is a constant which corrects for systematic errors such as can occur in blood background subtraction. This relationship is in the form for a straight line, $y = m x + c$, and the constants can be determined by the technique of least squares fitting a plot of Q_k against the integral given in equation 4. Once the constants m and C have been determined they can be used to calculate Q_k from equation 4 for the duration of the study. The uptake activity-time curve represents the accumulation of activity that would occur with no passage of urine. This is shown in Figures 3 and 4. Figure 3 shows a typical background activity-time curve flagged over the aorta (see Figure 2 for the flagged areas), and the curve of the accumulated total counts of the background. Each data point represents the number of counts accumulated over 15 seconds.

One kidney at a time is analyzed using SCAAR. After curve smoothing the background curve is multiplied by the kidney-to-background ratio (described earlier) to obtain the curve of the activity attributed to the background in the flagged area and then this curve is subtracted from the renogram curve to give a corrected renogram curve. Figure 4 a is the uptake component of the renogram (the background integral curve which has been corrected by the constants m and c).

Subtraction of the corrected renogram from the uptake component yields the removal component (the accumulated total of isotope which has left the kidney). (Figure 4). An additional calculation gives the smoothed rate of change with respect to time of the output curve. This can be calculated from the derivative of equation 4 or directly from the removal curve using equation 5.

$$\frac{dR(t)}{dt} = Q_b(t) - \frac{dK(t)}{dt} \qquad 5.$$

where R (t) is the removal component and
K (t) is the background corrected renogram curve.

THE ISOTOPE REMOVAL FACTOR

From the removal component and the extension of the uptake component, another number, the isotope removal factor (IRF) can be computed. This is a measure of the efficiency with which a kidney transfers isotope out of the kidney to the collecting system. This index is the percentage of the uptake component at time t which is removed after a time interval Δt, as determined from the removal component. This is

$$IRF = \frac{R(t + \Delta t)}{Q(t)} \times 100 \qquad 6.$$

The IRF is usually calculated after a time lapse long enough to insure that the IRF represents the actual clinical state of normal and most poorly functioning kidneys. SCAAR calculates an average IRF between 10 and 13 minutes for delays, Δt, of 2, 3, 4, 5 and 6 minutes. The IRF is discussed in detail by Britton and others. An additional computation gives the time of maximum accumulation of isotope in the kidneys.

CONCLUSION

SCAAR, the program described above, has the primary advantage of immediacy. Clinical information can be processed shortly after completion of the clinical study. Furthermore, it is relatively easy to incorporate new features into the program. This program is now being used regularly clinically.

Earlier work done with a multi-probe system and using a large computer in the analysis of the data has been successful. The program SCAAR represents an extension of this to a system involving an Anger Camera interfaced to a small computer, such as is now available in many medical facilities.

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ABSTRACT

SMALL COMPUTER ASSISTED ANALYSIS OF CAMERA RENOGRAMS

A program originally designed for 3 or 4 probe renography and a large computer has been adapted for use with a camera device interfaced to a small dedicated computer. The system combines the advantage of sequential imaging with the convenience of ready access to the computer by the physician.

Following the administration of ^{99m}Tc-human serum albumin, the patient can be accurately positioned with respect to the field of view of the camera. A static image allows calculation of relative blood background contribution to each kidney. Subsequently, serial imaging is performed, first with ^{131}I-Hippuran and then ^{99m}Tc-DTPA. The resultant time-activity curves derived from such studies are analyzed with the aid of the computer program. Information derived from such analysis includes time of maximum for each curve, the relative accumulation rate of radioactivity by each kidney, and efficiency of isotope removal from each kidney. The program offers the possibility of deriving quantitative information for comparative renal function. Further refinement of the analysis will be carried out following clinical evaluation.

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PROTOCOL FOR RENAL FUNCTION ANALYSIS

1. Scintiphoto of renal areas using background radiopharmaceutical. (See Figure 1).

2. Positioning of patient so kidneys visualized with enough room above them for background area.

3. Without moving the patient, injection of ^{131}I-Hippuran and then of ^{99m}Tc DTPA, sequential scintiphoto production.

4. Accurate selection of renal and background areas from dynamic study. (See Figure 2).

5. Utilization of selected areas (4) on background radiopharmaceutical scintiphoto (1) to calculate background subtraction factor.

6. Utilization of selected areas (4) on dynamic sequences (^{131}I-Hippuran + ^{99m}Tc-DTPA) to generate curves.

7. Five point smoothing and storing curves.

8. Background activity-time curve integration. (See Figure 3).

9. Individual renal background activity-time curve calculated from background area curve and subtraction factor calculated in (5).

10. Observed individual kidney time-activity curve generated in (6) minus individual background curve (9) gives "True kidney" curve.

11. Curve produced in(8)corrected by constants m and c to give least squares fit of some four points between 45 seconds and 2 minutes 45 seconds. Points chosen by eye to approximate best to overall observed slope. Least squares fit obtained is the isotope uptake component.

12. Subtraction of true kidney curve (10) from uptake component curve (11) to obtain removal component curve (12).

13. Determination of time of maximum accumulation of isotope in the kidney.

14. Calculation of the differential curve of the removal component (12) and smoothing.

15. Calculation of isotope removal factors ($I.R.F._S$) from ratios of (12) to (11) as discussed in the text.

16. Presentation to the clinician of (1) scintiphotos.
    (2) curves as in 6.
    (3) curves 10,11,12.
    (4) print out of results of 13.
    (5) print out of 15.

TABLE 1

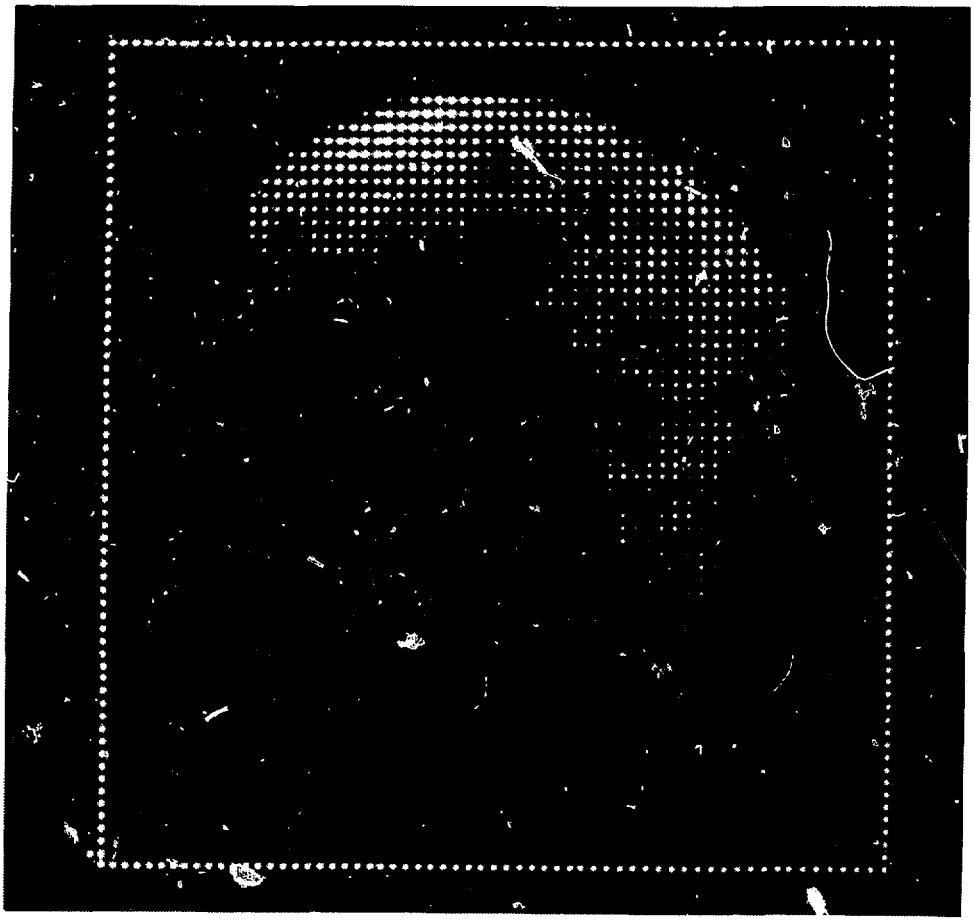

FIGURE 1

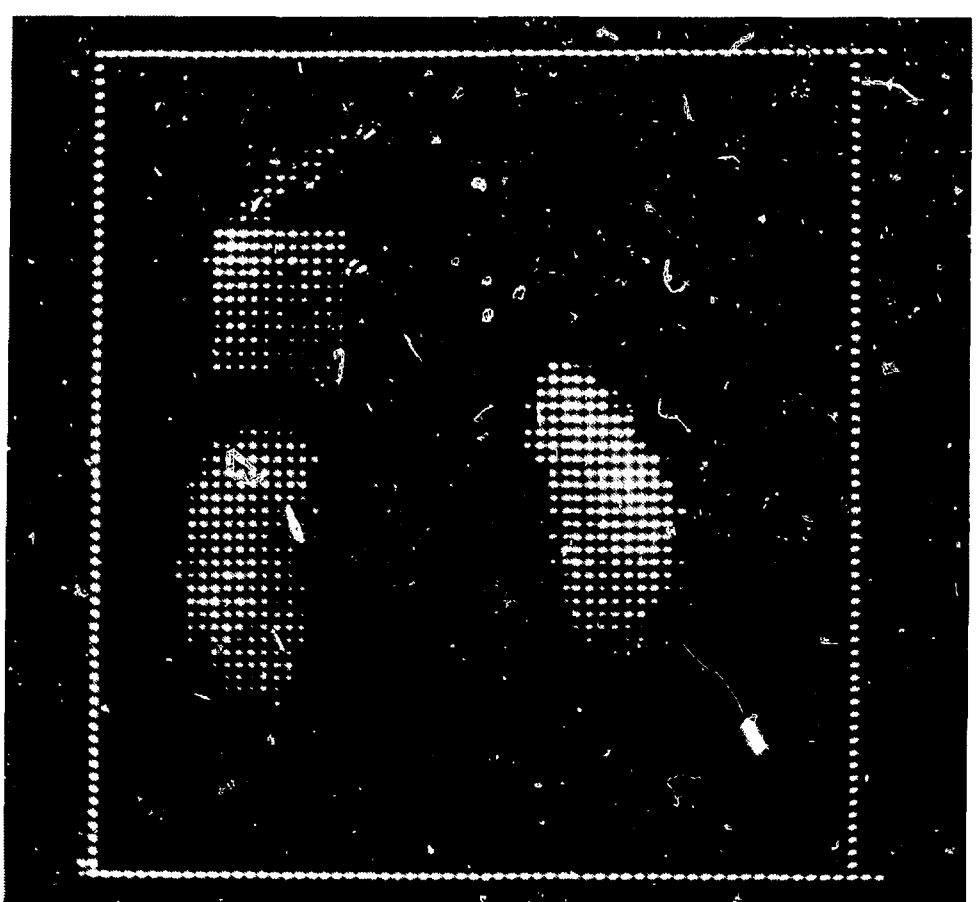

FIGURE 2

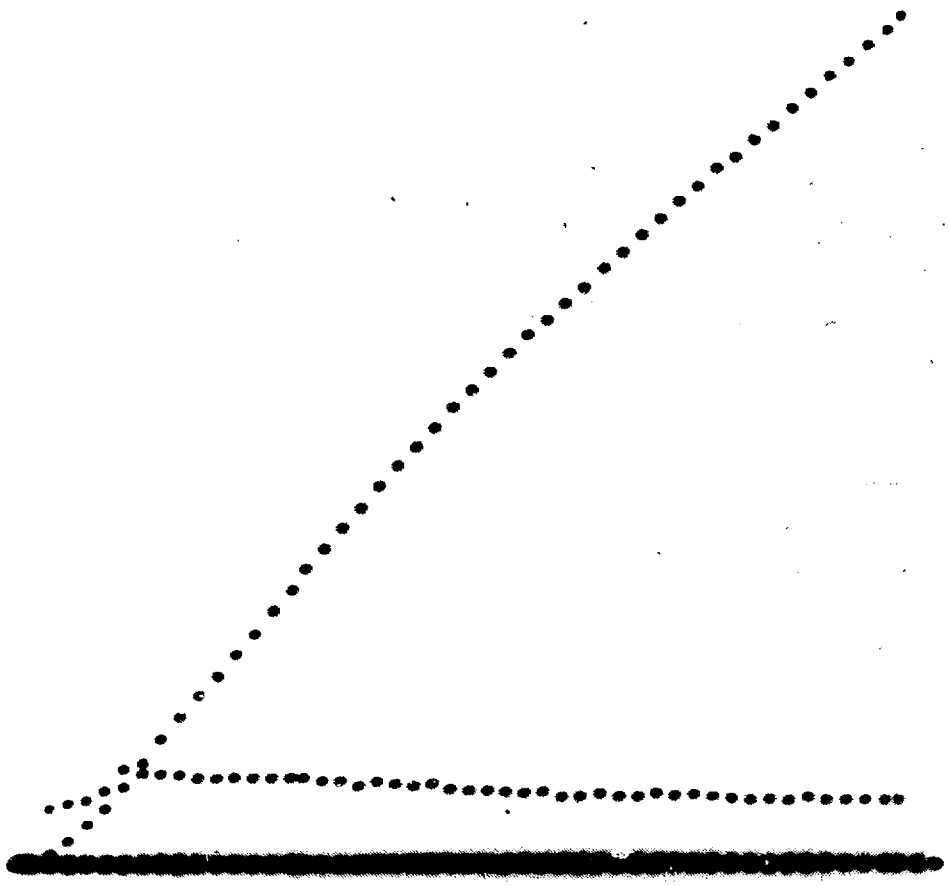

FIGURE 3

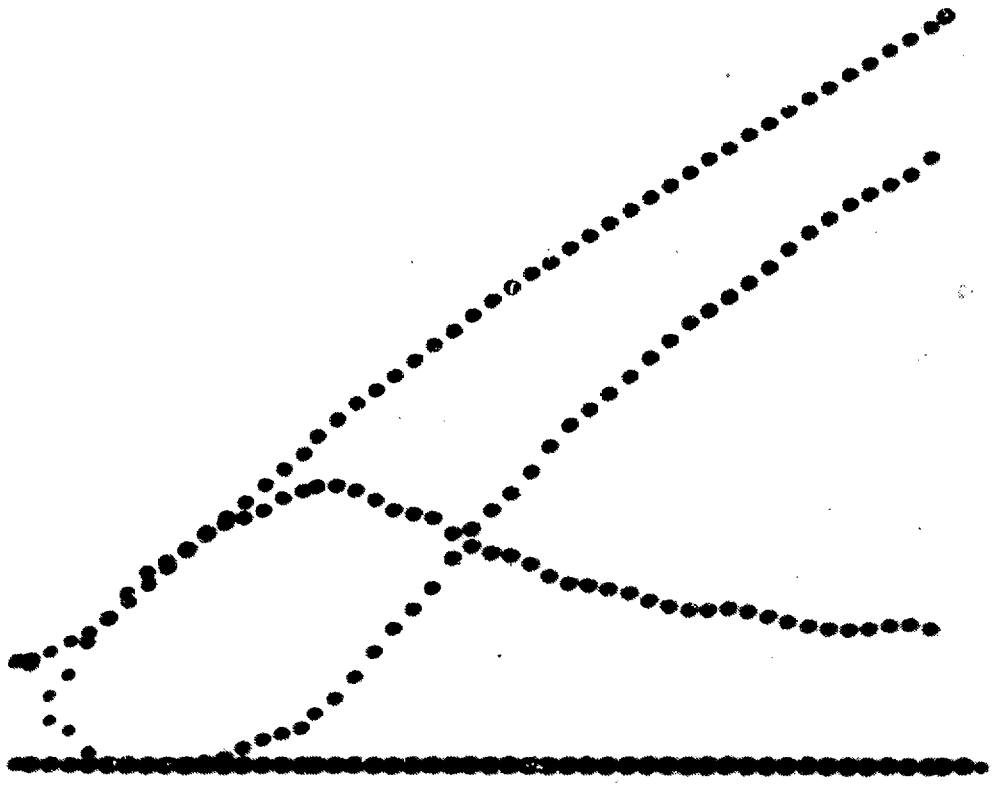

FIGURE 4

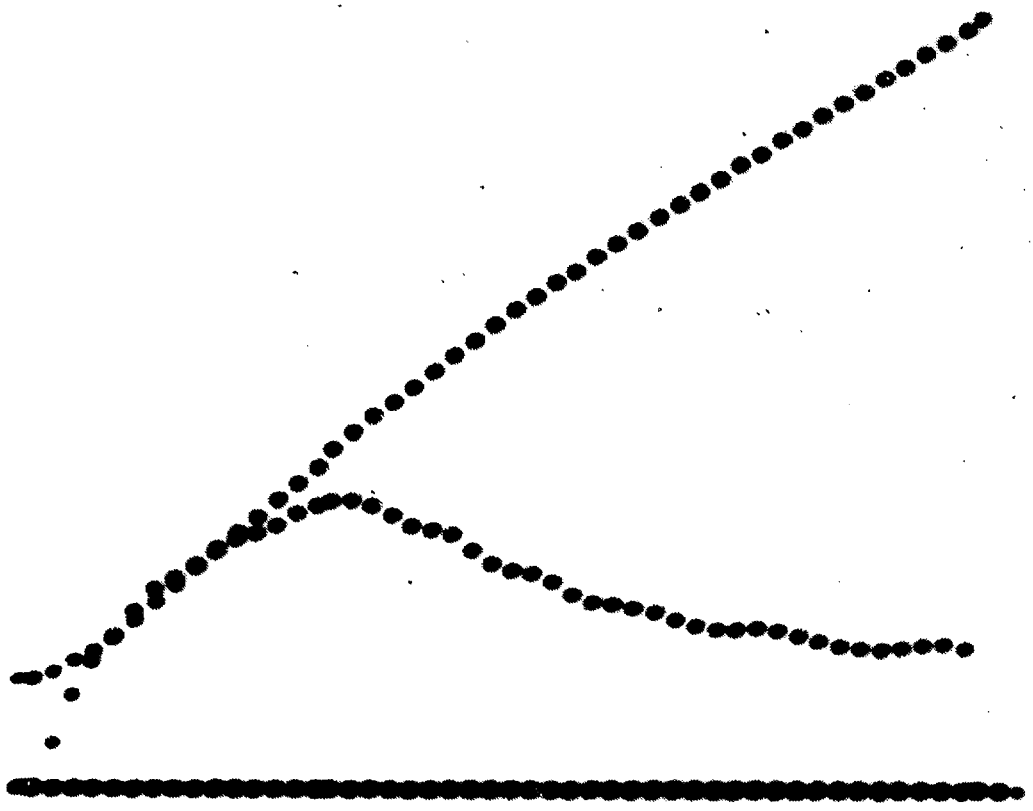

FIGURE 4a