

PATENT SPECIFICATION

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 (72) Inventor CHRISTOPHER ARCHIBALD GORDON LEMAY



(54) IMPROVEMENTS IN OR RELATING TO RADIOGRAPHY

(71) We, EMI LIMITED, a British company of Blyth Road, Hayes, Middlesex, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method of and apparatus for constructing a representation of the variation of absorption of a planar slice of a body with respect to penetrating radiation such as X or γ radiation.

The method and apparatus according to the invention can be used to assist in the production of radiographs in any convenient form, such as a picture on a cathode ray tube or other image forming device, a photograph of such a picture, or a map of absorption coefficients such as may be produced by a digital computer and on which contours may subsequently be drawn.

One method of, and apparatus for, constructing a representation of the variation of absorption of a planar slice of a body with respect to penetrating radiation is described in United States Patent No. 3,778,614. According to this specification, radiation is directed through part of the body, from an external source, in the form of a pencil beam. A scanning movement is imposed on the beam so that it takes up in turn a large number of differing dispositions, and a detector is used to provide a measure of the absorption of the beam in each such disposition after the beam has passed through the body. So that the beam takes up these various dispositions the source and the detector are reciprocated in a plane and are orbited about an axis normal to the plane. The various dispositions thus lie in a plane through the body over which the distribution of absorption coefficient for the radiation used is derived by processing the beam absorption data provided by the detector. The processing is such that the finally displayed distribution of absorption is the result of successive approximations.

The method and apparatus described in the aforesaid United States Patent has

proved to be successful for producing cross-sectional representation of parts of the living body, such as the head.

It is one object of this invention to provide an improved method of and apparatus for constructing a representation of the variation of absorption of a planar slice of a body with respect to penetrating radiation such as X or γ radiation which utilises a novel and advantageous technique of processing beam absorption data.

In a paper by G. N. Ramechanadran and A. V. Lakshminarayanan entitled "Three-dimensional reconstruction from Radiographs and Electron micrographs: Application of Convolutions instead of Fourier Transforms", and published in The Proceedings of the National Academy of Sciences, U.S.A., Vol. 68, No. 9 page 2236, September 1971, there is described a mathematical procedure which in principle is applicable to the reconstruction of cross sectional representations from absorption data such as that obtained from apparatus described in the aforesaid United States Patent. However the procedure, when reduced to practical application as described in the paper, does not yield accuracy and resolution to the degree required for examination of most parts of the human body.

It is another object of this invention to provide an improved method of and apparatus for constructing a representation of the variation of absorption of a planar slice of a body with respect to penetrating radiation such as X or γ radiation in which the processing of signals for many beams is carried out in overlapping time sequence in the same recirculating system.

According to a first aspect of the invention there is provided apparatus for examining a substantially planar section of a body by means of penetrating radiation, especially X- or γ -radiation, comprising a source of the radiation, a detecting arrangement for detecting radiation emergent from the section along at least one beam, scanning means arranged to cause said detecting arrangement to provide data signals representing the trans-

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mission or absorption of radiation passing through the section along sets of beams orientated at different angles in said section, and circuit means for constructing a representation of the transmission or absorption of said radiation at different locations in said section, the circuit means including storage elements corresponding to said locations and means for accumulating, in each storage element, signals derived from the data signals and relating to beams passing through or adjacent the corresponding locations, the improvement comprising; a signal modifying device having input and output connections and a recirculatory path linking said input and output connections, means for applying the data signals relating to a set of beams, in regular time sequence, to said input connection, a multiplying circuit for multiplying, by a factor less than unity, signals traversing said recirculatory path and for applying the product to said input connection and means for combining said product with the next signal in said sequence so that, as the data signals relating to a set of beams are applied sequentially to said input connection, output signals appear in succession at said output connection, each corresponding to a respective one of said data signals and some at least of said output signals including contributions from other data signals of the same set each of said contributions comprising a data signal multiplied by a respective one of a series of progressively diminishing factors, related to the spacing between the beam to which said respective one of said data signals relates and the beams to which said other data signals relate, means being provided for distributing the output signals so derived to the storage elements corresponding to the locations in said section intersected by the beam to which said respective one of said data signals relates.

According to a second aspect of the invention there is provided medical radiographic apparatus comprising means defining a patient position, a source of X-radiation, arranged to project said radiation through a substantially planar region of said patient position, scanning means for scanning said source relative to said patient position so as to project said radiation through said position along a plurality of sets of beams, the beams of a set being distributed across said region and each set being orientated at a respective angle to the patient position in said region, detector means for detecting the radiation emergent from said position along each of said paths and for producing data signals indicative of the amount of radiation projected through said position along each of said paths, means for processing said data signals to provide a representation of the absorption coefficient, with respect to said

radiation, at each of a plurality of locations distributed over said region; said processing means including at least one circuit having an input terminal and an output terminal, means for applying the data signals relating to a set of beams in sequence and at a predetermined rate to said input terminal, said at least one circuit including a delay line, having a delay related to said rate, an adding circuit, connected to said input terminal, through which said data signals pass before application to the input of said delay line, and a multiplying circuit, connected in the path of data signals which have traversed said adding circuit, and adapted to multiply signals applied thereto a factor less than unity, the components of said at least one circuit being interconnected so that a signal applied to said input terminal traverses said adding circuit and returns, duly multiplied to said adding circuit in time to be combined therein with the next data signal in the sequence; the output terminal being connected to the output of the adding circuit and thus receiving in sequence, as the data signals of a set are applied to said input terminal, output signals, each comprising one of said data signals combined with different proportions of any data signals of the same set previously applied to said circuit.

According to a further aspect of the invention there is provided apparatus for examining a substantially planar region of a body by means of penetrating radiation, such as X-radiation, including a scanning apparatus for providing data signals indicative of the amount of said radiation transmitted through said region along respective, substantially co-planar beam paths; a signal modifying device including a combining circuit and a recirculatory signal path having an input junction at said combining circuit; means for applying said data signals in a predetermined sequence to said combining circuit, said signal modifying device also including a multiplying circuit for multiplying, by a factor less than unity, signals traversing said recirculatory signal path and means for applying the product of said multiplication to said combining circuit in time to be combined with the next data signal in said sequence; means being provided for successively sampling the signals in said recirculatory signal path to provide output signals corresponding to said data signals, some at least of said output signals including a contribution from at least one other data signal, the contribution comprising said at least one other data signal multiplied at least once by said factor.

According to another aspect of the invention there is provided a method of examining a substantially planar region of a body by means of penetrating radiation, such as X-radiation, including the steps of:—

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(1) deriving data signals indicative of the amount of said radiation transmitted through said region along respective, substantially coplanar beam paths,

5 (b) applying said data signals in a predetermined sequence to the input of a recirculatory signal path,

(c) multiplying, by a factor less than unity, signals traversing said recirculatory signal path, to produce product signals,

10 (d) combining each product signal as it returns to the input of said recirculatory signal path, with the next data signal in said sequence applied thereto to produce combination signals,

15 (e) deriving from said recirculatory signal path output signals indicative of successively produced combination signals, and

20 (f) utilising said output signals to produce a representation of the variation in absorption of said radiation over said region.

In order that the invention may be more fully understood and readily carried into effect, it will now be described by way of example with reference to the accompanying drawings in which:—

25 Figure 1 illustrates diagrammatically the scanning mechanism of apparatus for examining a body by means of X radiation in accordance with one example of the present invention,

30 Figure 2 is a diagrammatic representation of the circuit for processing the signals derived from the scanning mechanism to convert them into signals representing the logarithmic absorption suffered by an exploring beam traversing many sets of parallel paths,

40 Figure 3 is a detailed block diagram of part of Figure 2 and

Figure 4 illustrates one practical form of data processor which can be utilised in the invention.

45 Referring to the drawings, the apparatus which is in a form adapted to examination of the head of the patient comprises a rotary member 1 which is rotatable inside a fixed casing 2 forming part of the main frame of the apparatus. The rotary member 1 has a central aperture 3 in which the head of the patient to be examined can be inserted. The central aperture is closed in a water-tight manner by a pouched cover 4 of flexible material which is secured to a sealing flange 5. This flange is held in sealing, but rotatable, relationship with the remote face of the member 1. The pouch is shown in section in Figure 1. The head of the patient is inserted through the aperture 3 into the pouch of the cover 4, and an additional head rest, not shown, may be provided to support the head in the pouch. A suitable chair or bed is provided to support the patient during the examination. When the head is inserted through the aperture 3 into

the pouch 4 it projects into a water reservoir 6 having side walls 7, the pouch separating the head from the water. The reservoir is closed at the front by the member 1 and cover 4, at the side by the walls 7 which 70 are made of plastic, and at the rear by a base wall, not shown. The walls 7 and the base wall rotate with the member 1, whereas the cover 4 with its flange 5 remains stationary, the flange being secured to the frame of the apparatus. A pipe 8 is connected to a pump for feeding water to and from the reservoir and after the patient's head has been inserted in the pouch, water is pumped into the reservoir 6 so as to expel the air from 80 between the pouch and the patient's head.

A toothed-gear wheel 9, driven by a motor 10 is provided for driving the rotatable member 1 so as to produce orbital scanning of the member 1 about its axis, which is also the axis of the aperture 3. The gearwheel 9 engages teeth formed around the inner periphery of the casing member 2. The rotatable member carries a source 11 of penetrating radiation, an X-ray generating tube in this example, and facing the source 11, on the other side of the aperture 3 there is provided an X-ray detector 12. The detector 12, which comprises a scintillating crystal and a photomultiplier, has a collimator 13. The source of the radiation 11 is arranged to be an effective point source and it has a collimator 14, the collimator 13 and 14 confining the radiation reaching the detector 12 to a single narrow beam 21 lying in a plane section normal to the axis of the rotary member 1. The plane lies within the reservoir 6. 95

The source 11 is secured to a toothed belt 15 driven by a toothed drive shaft 16 105 journaled in the rotatable member 1, the belt being extended between the shaft 16 and the second shaft 17 also journaled in the member 1. The shaft 16 is driven by a reversible motor 18, the controls of which are interlocked with those of the motor 10. Since the source 11 is massive, a counter balance weight, not shown, is provided secured to the other run of the belt so as to move reciprocally with the source. In operation of the apparatus, the source 11 and the collimator 14 are caused by the motor 18 to execute to and fro lateral scanning movements in the aforementioned plane normal to the axis of the rotary member 1. The detector 12 with its collimator 13 are coupled to the source 11 by a yoke 19 so that they execute the same lateral scanning movements. Guides 20 are provided to support the source and the yoke during the lateral scanning. Output signals are derived from the detector 12 during each lateral scan and these signals represent the transmission or absorption of the beam 21 along a sampling 125

set of closely spaced parallel beam paths in the planar section under examination.

The interlock between the motors 10 and 18 is such that following each lateral scan, in one or other direction, an increment of orbital movement of say 1° is imparted to the rotary member 1 by the motor 10. Thereafter another lateral scan occurs under the control of the motor 18 but this time in the reverse direction to the preceding lateral scan. A further set of output signals representing the transmission of the beam 21 along a further set of closely spaced parallel beam paths is derived, this set of beam paths being orientated at 1° relative to the preceding set. A photocell device, represented diagrammatically by the block 22, and co-operating with a graticule, not shown, coupled to the yoke 19, is provided to monitor the lateral scanning displacements and determine the timing of the output signals. The alternate orbital and lateral scanning movements are continued until a total movement of 180° has been completed.

As indicated in Figure 1, the reservoir 6 has a lateral extent substantially equal to that of the lateral scan, the extremities of which are indicated by the dotted beams 21' and 21''. It projects to either side of the aperture 3 so that at the beginning of each lateral scan the beam 21 is for a time traversing a known path length through the water in the reservoir. The reservoir, when filled with water, thus provides a reference attenuator so positioned relative to said locating means as to provide a known attenuation of the beam 21 at the beginning of each lateral scan before the beam passes to the body to be examined. As will appear subsequently a reference signal is derived from the detecting means while the beam is intercepted by the water reservoir and this reference signal is utilised for modifying output signals derived when the beam is intercepted by the body to be examined. As the walls of the reservoir, other than the cover 4, rotate with the member 1, the path of the beam through the reference attenuator provided by the side portions of the reservoir 6 is substantially the same for every lateral scan regardless of the angular orientation. There is also provided mounted on the member 1 a block of lead 23 which is located at one extremity of the lateral scans carried out by the source 11 and detector 12. The lead block 23 provides substantially complete absorption of the X-radiation and the output signal from the detector 12 when the beam is intercepted by the lead provides a second reference signal which is utilised to modify the signals derived from the detector not only when the beam 21 is intercepted by the body to be examined, but also when it is intercepted by the parts of the reservoir

which act as reference attenuators. It is to be noted that the reservoir 6 provides attenuation of the beam 21 throughout the lateral scanning movements, but the attenuation is reduced in the regions where the beam is liable to be intercepted by the body to be examined. The attenuation or absorption coefficient of water is such that the total absorption of the beam 21 is approximately the same throughout each lateral scan, when the body to be examined is positioned in the pouch (except of course when the beam is intercepted by the lead block 23). In the circuit for processing the output signals of the detector 12 the logarithm of the reference signal derived when the beam suffers the known attenuation at the beginning of each lateral scan is subtracted from the logarithm of the other output signals, and the resultant output signals represent substantially only differences in the attenuation of the beam within the body examined from that of transmission through water.

A reference detector 24 is mounted close to the X-ray source 11 so that it receives radiation directly from the source via a collimator 25. The detector 24 is provided to monitor the energy of the X-rays.

The circuit of the apparatus set out in Figure 2 commences with the detectors 12 and 24 of the mechanism that has been described with reference to Figure 1. The output signals of the detector 12 are applied to a gate 30 which is opened at predetermined times by sampling pulses from a master control circuit 31. This master control circuit receives input signals from the photocell device 22 and feeds out suitable control signals not only to the gate 30 but also to the motor 10 and to the reversing motor 18. The sampling pulses which it feeds to the gate 30 are produced at times determined by the aforesaid graticule so as to derive from the detector 12 a succession of output signals corresponding to the transmission of the beam 21 through a sampling set of parallel beam paths, as already indicated. The orientation for the set of paths is determined by the angular position of the rotatable member 1. During each sampling interval the output of the detector 12 is integrated in an integrator 32 and then converted to digital code form in an analogue-to-digital converter 33. The signal generated during each sampling pulse is stored in its digital form in a store 34. The X-ray beam 21 is intercepted by the lead block 23 once in two lateral scans and therefore the corresponding output signal from the detector 12 is stored for the duration of two traverses. The signals of a particular parallel set of paths in the store 34 include those obtained when the X-ray beam 21 is known to pass through the reference paths in the reservoir 6 and those obtained when

passing through the body under examination. Gate 35 is provided for selecting the output signal derived from the detector at the time when the beam 21 is substantially interrupted by the lead block 23. Another gate 36 is provided for selecting the signals derived at other traversal times. The section is controlled by sampling pulses derived from the master control circuit 31 in such a way that the reference signal representing the virtually complete attenuation introduced by the lead is subtracted from each other signal of a sampling set, so that after the subtraction the resulting signals represent the transmission or absorption of the beam 21 within the examined body related to the absorption of lead as a datum. In this way the effect of 'after glow' in the detector 12 is largely removed. The resulting signals are passed into dividing circuit 38.

The reference detector 24 previously referred to has an output gate 40 which receives sampling pulses from the master control circuit 31, coincident with the sampling pulses applied to the gate 30. Signals passing through the gate 40 are integrated in an integrator 41 and converted to digital form in a converter 42, these components 41 and 42 corresponding to the integrator 32 and converter 33. The digitised signals from the detector 24 are then passed to a store 43 and applied thence to the aforesaid dividing circuit 38.

In the dividing circuit each signal from the detector 12 is divided by the corresponding signal from the store 43 to compensate for variations in energy of the source 11. The signals so compensated are passed to a log converting circuit 45 which translates each signal from the detector 12, referenced on lead as the datum as explained, into its logarithm and holds them in this form. These signals are applied to two gates 46 and 47 which are controlled by pulses from the master control circuit 31. The gate 46 is opened at times corresponding to those when the X-ray beam 21, during any particular traverse, is passing through the region in which the body to be examined may be located, while the gate 47 is opened at other times corresponding to when the beam 21 is passing through the reference paths in the water and is therefore subjected to a known attenuation. The signals from the gate 47 may therefore be termed reference signals, those from the gate 46 being distinguished as output signals. The reference signal moreover is read out repeatedly to coincide with each output signal of a particular scan, and it is subtracted from these output signals so that the output signals then represent the ratio of the attenuation of the beam 21 to the known attenuation produced by the water in the reservoir. Any spurious variations in the output signals, due to rapid

drift of the sensitivity of the detector 12 are thus substantially compensated. The output signals after these modifications are fed to the signal processor 50 to participate along with the output signals of all the other sets in the image reconstruction of the distribution of absorption of the exploring radiation in the section of the body under examination.

In the complete specification of co-pending Application No. 19528/73 Serial No. 1,471,531 from which this application was divided, there is disclosed an arrangement for the signal processor 50 which effects a form of convolution on the output signals. The signals so convolved are then suitable for combination in a layergram type of format to produce the required variation of absorption. In the convolution, each output signal is modified by combining it with different proportions of other output signals relating to paths substantially parallel to the path to which the output signal being modified relates, the proportions being determined in accordance with a function which varies with the spacing between the path giving rise to the output signal being modified and the paths giving rise to the output signals to be combined therewith. In practice the proportions are applied in the form of a series of so-called "L-factors" which are discrete values of the said function.

In order to more clearly explain the sequence of procedure involved in the convolution the process will first be described with the aid of the simplified block diagram of Figure 3.

In Figure 3 the numeral 239 designates a store from which beam absorption data is stored in the form of parallel sets as already referred to. An address selector 251 for deriving outputs from the store 239 is also depicted, as is a processed data store 253 holding processed data from the convolution processor 252 to be understood as operating after the linear convolution manner described in the complete specification of Application No. 19528/73, Serial No. 1,471,531.

To consider the use of the store 253, suppose that the absorption data values relative to the exploring beams of a parallel set are

$$E_0, E_1, E_2, E_3, \dots$$

respectively in the order in which the beams occur across the set. Moreover suppose that the sequence of terms

$$L_0, L_1, L_2, L_3, \dots$$

is the sequence constituting the L-factors series, and consider that the value E_n has been drawn from the store 239. This value is

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multiplied separately by each of the terms of the L-factor series in the data processor 252 and the products

$$E_0L_0, E_0L_1, E_0L_2, E_0L_3, E_0L_4, \dots, E_0L_w$$

are respectively stored at addresses

$$A_0, A_1, A_2, A_3, A_4, \dots, A_w$$

in section 253 of the processed data store 253 under the control of the address selection 251. Then consider the value E_1 to be withdrawn from 239 and likewise multiplied by the terms of the L-factor series in the data processor 252, to produce the products

$$E_1L_0, E_1L_1, E_1L_2, E_1L_3, \dots, E_1L_{w-1}$$

These products are stored respectively at the addresses

$$A_1, A_2, A_3, A_4, \dots, A_w$$

in section 253' of the store 253, being added to the products already stored at these addresses. Next, withdrawing the value E_2 from the store 239 and following the same multiplication procedure, the products

$$E_2L_0, E_2L_1, E_2L_2, \dots, E_2L_{w-2}$$

are stored respectively and additively at the addresses

$$A_2, A_3, A_4, \dots, A_w$$

The process is continued in this way until all the absorption values of the parallel set have been used up. When this stage is reached the magnitude stored in address A_0 will be

$$S_0 = E_0L_0,$$

that in address A_1 will be

$$S_1 = E_1L_0 + E_0L_1,$$

that in address A_2 will be

$$S_2 = E_2L_0 + E_1L_1 + E_0L_2,$$

that in address A_3 will be

$$S_3 = E_3L_0 + E_2L_1 + E_1L_2 + E_0L_3,$$

and so on, following this pattern.

In a next stage of the procedure, the absorption values are drawn from the store 239 in a like way, but in the reverse order to that in which they were previously taken. As so taken in reverse order, they are processed in identical manner as before except that the addresses in section 253' of the

store 253 are also used in the reverse order. This is depicted in Figure 3.

Finally the values

$$E_0L_0, E_1L_0, E_2L_0, E_3L_0, E_4L_0, \dots, E_wL_0$$

are subtracted respectively from the magnitudes already accumulated at the addresses

$$A_0, A_1, A_2, A_3, A_4, \dots, A_w$$

to yield an ultimate set of magnitudes at these addresses. This procedure is continued for the absorption values corresponding to every parallel set of beams, the set of magnitudes for each set of parallel beams being accumulated in a different section of the store 253. The preferred final processing of the accumulated magnitudes to yield the required image reconstruction will be referred to subsequently. The process which has been described of accumulating magnitudes may be described as deriving for each beam data signal a summation signal which when used to form a layergram produces a compensated layergram.

The series of operation which is depicted with reference to Figure 3 is essentially that described and claimed in the complete specification of Application No. 19528/73, Serial No. 1,471,531, and can be carried out by a suitable programmed digital computer, but in the present invention, the L-factor data processor takes the form of a special computer in which the L-factors are generated implicitly in the terms of a time series produced by circuits which also perform the multiplication generating the products which are transferred to the store 253. This can be done since all or most of the L-factors can be approximated as a limited set of exponential terms, this being possible since the L-factors approximate in general to a slowly varying monotonic function. Figure 4 of the accompanying drawings shows the general form of a circuit operating on these lines.

In this figure, 210 is a path carrying beam absorption data in digital form as withdrawn from the beam data store 239 of Figure 3 by the address selector 251. From 210 this data is distributed via a path 211 to the inputs of a number of similar circuits such as those included within the rectangles shown in broken line and designated 212¹ and 212². The outputs of these circuits also in digital form are fed to a common output path 213 via an adder circuit 214 and the transformed data as it appears at conductor 213 is suitable for transfer to, and storage in, any section such as 253' of the store 253 of Figure 8 in accordance with the procedure outlined with reference to that figure. The generation and character of these contributions will become more clear with the des-

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 cription of the circuits such as 212¹ and 212².

$$a_k = \log A_k,$$

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 Considering circuit 212¹ as typical of these circuits, an absorption data signal appearing on path 210 is fed via 211 to the adder circuit 215¹ and thence to the input of the digital delay line 216¹, from which the signal emerges with a delay equal to the period between clock pulses of a master clock pulse source used to control all the circuits 212¹, 212², ... The use of such clock pulse source is well known and has not been illustrated. The initial absorption data signal is timed so that its appearance on the path 210 is synchronised with an initial, or reference, clock pulse for one parallel set. Assuming this is the signal E₀ referred to above, the other signals E₁, E₂ etc. of the parallel set appear on the path 210 synchronously with successive clock pulses. The signal emergent from the delay line 216¹ is applied to multiplier circuit 217¹, which multiplies the signal by a numeral less than unity, and feeds the signal so multiplied back to the adder circuit 215¹ via the other of its two inputs, thence to be applied to the input of the digital delay line 216¹. The signal then recirculates the loop 216¹, 217¹, 215¹, to perform a further recirculation, and so on for a number of times equal to the number, less one, of data signals forming a parallel set and therefore for the number of L-factors utilised after L₀. The output from the circuit is taken from the output of the adder circuit 215¹ and applied via conductor 218¹ to the multiplier circuit 219¹.

where A_k is the multiplying factor, less than unity, of the multiplier 217^k of the circuit 212^k, and B_k is the multiplying factor of the multiplier 219^k of the circuit. If there are n circuits of which the circuit 212^k is typical then at the time mentioned, which may be referred to as time t(r), the output at conductor 213 due to the application of the signal E₀ to the circuit must be of value

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$$E_0 \sum_{1k}^n B_k e^{a_k r} = E_0(r)$$

Thus the circuit of Figure 4 can be made to generate the series of signals E₀(r) at the times t(r) consequent upon the application of the signal E₀. It is found that by suitable choice of the multiplying factors such as A^k and B_k, the series of signals E₀(r) synchronised with the successive clock pulses may be made to approximate numerically to a high degree of accuracy, at least for all values except a few initial terms, to the series

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$$E_0 L_0, E_0 L_1, E_0 L_2, \dots, E_0 L_r, \dots,$$

where the L's are the series of L-factors for the system. A few early terms of the series E₀(r), namely say E₀(1), E₀(2), E₀(3), may not correspond sufficiently accurately to the required values

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$$E_0 L_1, E_0 L_2, E_0 L_3,$$

due to the initial factors L₁, L₂ and L₃ being not sufficiently accurately approximated, but they may be made to do so by adjustment, and such limited adjustment is simple in terms of operation of the digital computer. Five circuits such as 212_k are used, it being found in practice that if n=5 then with the exception of a few early terms which may be corrected as indicated, all terms may be generated with an accuracy corresponding to that in the final image reconstruction of about one part in a thousand.

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 The output of the multiplier 219¹ is applied to the input of the adder circuit 214 via path 220¹, where the output is added to that of circuit 212² and the output of other such circuits. As signals appear in the output of the adder circuits 215¹, 215², . . . , with the occurrence of successive clock pulses, a series of signals is fed out via path 213. When the series has continued for a time specified by the number of L-factors utilised it can be terminated by clearing the delay lines of the circuits 212¹, 212², . . . , and a new series can then be started.

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 In regard to the operation of the group of circuits 212¹, 212², . . . , consider the operation of any one of them, say circuit 212^k. As indicated the absorption data signal applied to the group to start the generation of the series of signals at the group output conductor 213 is of value E₀. Then considering only the subsequent history of the signal E₀, it may be shown that the output of the circuit 212^k via its output conductor 220^k at a time r clock pulse periods after the application of the signal E₀ that is at clock pulse r+1 is of value

$$E_0 B_k e^{a_k r}$$

in which the expression

$$S_0, S_1, S_2, S_3, \dots$$

described earlier. In conformity with this

earlier description when the series is completed and the delay lines have been cleared, the same set of absorption data signals is fed into the circuit again by the address selector 251, but in the reverse order to generate another such series. With the generation of each of the series, the terms of the series are fed to the store 253 in the way earlier explained. Finally signals proportional to

$$E_0L_0, E_1L_0, E_2L_0, E_3L_0, E_4L_0, \dots$$

are fed to the addresses of the store so that the convolution process is completed correctly. These operations are all controlled and carried out in known manner by the digital computer, of which the circuit of Figure 4 is a part. Thus the store section concerned say 253', is finally filled for transfer to an output matrix store the step by step accumulation being accomplished by the recirculations of the data in the circuit of Figure 3.

With regard to possible errors in the values of L_1, L_2, L_3 these errors if significant are preferably dealt with as follows. Assume that the errors are respectively

$$\Delta L_1, \Delta L_2, \Delta L_3,$$

then these errors are stored in the digital computer. Assume also that some beam datum value E_j has been applied to the circuit of Figure 3, the suffix j signifying that the datum is relevant to the j th beam of a parallel set. Then a correction of value

$$E_j\Delta L_1$$

is fed additively by the computer to store at the addresses A_{j-1} and A_{j+1} of the store section corresponding to the set. Moreover the correction value

$$E_j\Delta L_2$$

is fed likewise to the store section at addresses A_{j-2} and A_{j+2} . Likewise the correction value

$$E_j\Delta L_3$$

is similarly fed to addresses A_{j-3} and A_{j+3} . The principle of this procedure is followed for all values j of the set and for all sets.

While processing of the sets of data according to Figure 4 may be performed in a serial mode, taking parallel sets of absorption data in turn and applying them to a single processor of recirculation type as in Figure 4, all these sets may be processed simultaneously in parallel by providing and programming a separate recirculation type circuit for processing each parallel set of

data. This can give very rapid processing of the data, if this is required.

Although the invention is preferably carried out using the digital delay circuit of Figure 4, it may also be carried out without the actual use of such circuits by employing a standard computer to simulate them. The time saving in processing may not then be so great, but is nevertheless useful.

Where reference is made herein and in the claims to producing or constructing a representation of the variation of absorption of a planar slice it will be understood that the quality represented need not be the absorption explicitly, and the representation may be of some function of absorption (such as transmission of the radiation) or may be of differences of absorption.

WHAT WE CLAIM IS:—

1. Apparatus for examining a substantially planar section of a body by means of penetrating radiation, especially X- or γ -radiation, comprising a source of the radiation, a detecting arrangement for detecting radiation emergent from the section along at least one beam, scanning means arranged to cause said detecting arrangement to provide data signals representing the transmission or absorption of radiation passing through the section along sets of beams orientated at different angles in said section, and circuit means for constructing a representation of the transmission or absorption of said radiation at different locations in said section, the circuit means including storage elements corresponding to said locations and means for accumulating, in each storage element, signals derived from the data signals and relating to beams passing through or adjacent the corresponding locations the improvement comprising; a signal modifying device having input and output connections and a recirculatory path linking said input and output connections, means for applying the data signals relating to a set of beams, in regular time sequence, to said input connection, a multiplying circuit for multiplying, by a factor less than unity, signals traversing said recirculatory path and for applying the product to said input connection and means for combining said product with the next signal in said sequence so that, as the data signals relating to a set of beams are applied sequentially to said input connection, output signals appear in succession at said output connection, each corresponding to a respective one of said data signals and some at least of said output signals including contributions from other data signals of the same set each of said contributions comprising a data signal multiplied by a respective one of a series of progressively diminishing factors, related to the spacing between the beam to which said respective one of said



earlier description when the series is completed and the delay lines have been cleared, the same set of absorption data signals is fed into the circuit again by the address selector 251, but in the reverse order to generate another such series. With the generation of each of the series, the terms of the series are fed to the store 253 in the way earlier explained. Finally signals proportional to

10 $E_0L_0, E_1L_0, E_2L_0, E_3L_0, E_4L_0, \dots$

are fed to the addresses of the store so that the convolution process is completed correctly. These operations are all controlled and carried out in known manner by the digital computer, of which the circuit of Figure 4 is a part. Thus the store section concerned say 253', is finally filled for transfer to an output matrix store the step by step accumulation being accomplished by the recirculations of the data in the circuit of Figure 3.

With regard to possible errors in the values of L_1, L_2, L_3 these errors if significant are preferably dealt with as follows. Assume that the errors are respectively

$$\Delta L_1, \Delta L_2, \Delta L_3,$$

then these errors are stored in the digital computer. Assume also that some beam datum value E_j has been applied to the circuit of Figure 3, the suffix j signifying that the datum is relevant to the j th beam of a parallel set. Then a correction of value

$$E_j\Delta L_1$$

is fed additively by the computer to store at the addresses A_{j-1} and A_{j+1} of the store section corresponding to the set. Moreover the correction value

$$E_j\Delta L_2$$

is fed likewise to the store section at addresses A_{j-2} and A_{j+2} . Likewise the correction value

$$E_j\Delta L_3$$

is similarly fed to addresses A_{j-3} and A_{j+3} . The principle of this procedure is followed for all values j of the set and for all sets.

While processing of the sets of data according to Figure 4 may be performed in a serial mode, taking parallel sets of absorption data in turn and applying them to a single processor of recirculation type as in Figure 4, all these sets may be processed simultaneously in parallel by providing and programming a separate recirculation type circuit for processing each parallel set of

data. This can give very rapid processing of the data, if this is required.

Although the invention is preferably carried out using the digital delay circuit of Figure 4, it may also be carried out without the actual use of such circuits by employing a standard computer to simulate them. The time saving in processing may not then be so great, but is nevertheless useful.

Where reference is made herein and in the claims to producing or constructing a representation of the variation of absorption of a planar slice it will be understood that the quality represented need not be the absorption explicitly, and the representation may be of some function of absorption (such as transmission of the radiation) or may be of differences of absorption.

WHAT WE CLAIM IS:—

1. Apparatus for examining a substantially planar section of a body by means of penetrating radiation, especially X- or γ -radiation, comprising a source of the radiation, a detecting arrangement for detecting radiation emergent from the section along at least one beam, scanning means arranged to cause said detecting arrangement to provide data signals representing the transmission or absorption of radiation passing through the section along sets of beams orientated at different angles in said section, and circuit means for constructing a representation of the transmission or absorption of said radiation at different locations in said section, the circuit means including storage elements corresponding to said locations and means for accumulating, in each storage element, signals derived from the data signals and relating to beams passing through or adjacent the corresponding locations the improvement comprising; a signal modifying device having input and output connections and a recirculatory path linking said input and output connections, means for applying the data signals relating to a set of beams, in regular time sequence, to said input connection, a multiplying circuit for multiplying, by a factor less than unity, signals traversing said recirculatory path and for applying the product to said input connection and means for combining said product with the next signal in said sequence so that, as the data signals relating to a set of beams are applied sequentially to said input connection, output signals appear in succession at said output connection, each corresponding to a respective one of said data signals and some at least of said output signals including contributions from other data signals of the same set each of said contributions comprising a data signal multiplied by a respective one of a series of progressively diminishing factors, related to the spacing between the beam to which said respective one of said



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data signals relates and the beams to which said other data signals relate, means being provided for distributing the output signals so derived to the storage elements corresponding to the locations in said section intersected by the beam to which said respective one of said data signals relates.

2. Apparatus according to claim 1 including means for applying each set of signals twice to the signal modifying device, the order of the sequence being reversed for the second application as compared with the first so that two sets of summation signals are applied to said storage elements, allowance being made for duplication of signals distributed to some of said storage elements.

3. Apparatus according to either of the preceding Claims including at least one further signal modifying device, similar to the first mentioned signal modifying device except that the said multiplying factor is different, means for applying said data signals in parallel to each of said devices and means for combining the output signals appearing contemporaneously at the output connections of said devices.

4. Medical radiographic apparatus comprising means defining a patient position, a source of X-radiation, arranged to project said radiation through a substantially planar region of said patient position, scanning means for scanning said source relative to said patient position so as to project said radiation through said position along a plurality of sets of beams, the beams of a set being distributed across said region and each set being orientated at a respective angle to the patient position in said region, detector means for detecting the radiation emergent from said position along each of said paths and for producing data signals indicative of the amount of radiation projected through said position along each of said paths, means for processing said data signals to provide a representation of the absorption coefficient, with respect to said radiation, at each of a plurality of locations distributed over said region; said processing means including at least one circuit having an input terminal and an output terminal, means for applying the data signals relating to a set of beams in sequence and at a predetermined rate to said input terminal, said at least one circuit including a delay line, having a delay related to said rate, an adding circuit, connected to said input terminal, through which said data signals pass before application to the input of said delay line, and a multiplying circuit, connected in the path of data signals which have traversed said adding circuit, and adapted to multiply signals applied thereto by a factor less than unity, the components of said at least one circuit being interconnected so that a signal applied to said input terminal transverses said adding

circuit and returns, duly multiplied, to said adding circuit in time to be combined therein with the next data signal in the sequence; the output terminal being connected to the output of the adding circuit and thus receiving, in sequence, as the data signals of a set are applied to said input terminal, output signals, each comprising one of said data signals combined with different proportions of any data signals of the same set previously applied to said circuit.

5. Apparatus according to Claim 4 including a further multiplying circuit connected to said output terminal and adapted to multiply said output signals by a substantially constant factor.

6. Apparatus for examining a substantially planar region of a body by means of penetrating radiation, such as X-radiation, including a scanning apparatus for providing data signals indicative of the amount of said radiation transmitted through said region along respective, substantially co-planar beam paths; a signal modifying device including a combining circuit and a recirculatory signal path having an input junction at said combining circuit; means for applying said data signals in a predetermined sequence to said combining circuit; said signal modifying device also including a multiplying circuit for multiplying, by a factor less than unity, signals traversing said recirculatory signal path and means for applying the product of said multiplication to said combining circuit in time to be combined with the next data signal in said sequence; means being provided for successively sampling the signals in said recirculatory signal path to provide output signals corresponding to said data signals, some at least of said output signals including a contribution from at least one other data signal, the contribution comprising said at least one other data signal multiplied at least once by said factor.

7. An apparatus, for examining a body, substantially as herein described with reference to Figure 4 of the accompanying drawings.

8. A method of examining a substantially planar region of a body by means of penetrating radiation, such as X-radiation, including the steps of:—

(a) deriving data signals indicative of the amount of said radiation transmitted through said region along respective, substantially co-planar beam paths,

(b) applying said data signals in a predetermined sequence to the input of a recirculatory signal path,

(c) multiplying, by a factor less than unity, signals traversing said recirculatory signal path, to produce product signals,

(d) combining each product signal as it returns to the input of said recirculatory

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signal path, with the next data signal in said sequence applied thereto to produce combination signals,

5 (c) deriving from said recirculatory signal path output signals indicative of successively produced combination signals, and

(f) utilising said output signals to produce

a representation of the variation in absorption of said radiation over said region.

9. A method, of examining a body, substantially as herein described with reference to Figure 4 of the accompanying drawings. 10

A. B. LOGAN,
Chartered Patent Agent.

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