

PATENT SPECIFICATION

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(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:—

The present invention relates to radiography and it relates especially, though not exclusively, to that branch of radiography which has become known as computerised axial tomography, or briefly C.A.T. An apparatus capable of performing C.A.T. ascertains the absorption suffered by penetrating radiation, such as X-radiation, on traversing a plurality of substantially linear paths through a cross-sectional slice of the body. The absorption values so ascertained are processed to evaluate the absorption (or transmission) coefficient with respect to said radiation at each of a plurality of elemental areas distributed over the slice. Such an apparatus is described in British Patent Specification No. 1,293,915.

It has been usual hitherto to ascertain the aforementioned absorption values by detector means, including one or more collimated detector devices; the collimation being effected to prevent, so far as is practicable, the detection of scattered radiation. In these arrangements, the measurement of absorption of radiation along the various paths is typically effected by scanning the detector means mechanically with respect to the body. The scanning typically involves lateral and rotational scanning movements.

However it has recently been proposed, for example in British Patent Specification No. 1,529,799 and in British Patent Application No. 43,984/75, (Serial No. 1,558,062), that a source of X-radiation be rapidly scanned laterally relative to the body by electrical or electro-magnetic deflection of a beam of electrons over an X-ray emitting target. When such rapid lateral scanning of the source is employed, it is inconvenient and practically difficult to cause the detector means to follow the movement, and it has therefore been the practice to use a fixed bank of detector devices

relative to which the source is scanned. In the interest of rapid data acquisition, the source of radiation is arranged to produce a fan-like substantially planar spread of radiation which overlaps a substantial number of the detector devices. This means, however, that some of the detector devices, particularly those in the centre of the array, are irradiated whilst the source is scanned over a substantial range of positions and thus, if collimators are used, they must be wide enough to accept radiation from all positions in said range. The widening of the collimators, however, can permit in some circumstances the detectors of more scattered radiation than is acceptable, and also gives rise to practical problems in that the collimator for one detector device tends to intercept radiation which should be collected by neighbouring detector devices.

It is an object of this invention to reduce the difficulties and the apparently conflicting requirements imposed by the foregoing considerations.

According to the invention there is provided radiographic apparatus including a source of penetrating radiation, such as X-radiation, arranged to project radiation through a cross-sectional slice of a body, detector means disposed to receive radiation emergent from the posed to receive radiation emergent from the body and processing means for operating on output signals, provided by said detector means and indicative of the absorption suffered by said radiation on traversing substantially linear paths through said slice, to evaluate absorption coefficients for a plurality of elemental areas distributed over said slice, said processing means including compensating means for adjusting said evaluated coefficients to allow for the detection, by said detector means, of scattered radiation.

In order that the invention may be clearly understood and readily carried into effect, one embodiment thereof will now be described, by way of example only, with reference to the drawings accompanying the Provisional Specification of which:—

Figure 1 shows, in front elevational view,

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part of an apparatus which incorporates one example of the invention, and

Figure 2 shows, in flow diagram form, a manner in which coefficients assigned to elemental areas can be compensated for the effects of scatter.

Referring now to Figure 1, a body 1 to be examined is supported supine on a semi-cylindrical couch 2 of unitary construction, and is secured to the couch 2 by means of one or more straps 3 which are secured to the outside of the bed 2 as shown. Both the bed and the strap are made of material which is substantially transparent to X-radiation, and a suitable packing material 4 having an absorption similar to that of the body 1 is disposed in gaps between the body 1 and the couch 2 in order that the body is not surrounded by a layer of air, which exhibits markedly different absorption to X-radiation to human tissue. Suitable packing material is water in a flexible bag, or alternatively viscous or particulate material in one or more flexible bags can be used.

The part of the body 1 which is of interest is located in an aperture 5 in a turntable member 6 which is arranged to rotate around the body 1 about an axis 7 which extends perpendicularly to the plane of the paper (i.e. a horizontal axis in practice). The turntable member 6 carries an X-ray source 8 and array 9 of radiation detectors, and the member 6 and its attachments are rotated by means of a gear wheel 10 driven by an electric motor 11. The wheel 10 engages teeth (not shown) formed all around the periphery of member 6. The detectors 9 can be of any suitable kind, for example scintillation crystals with associated photomultiplier scintillation crystals with associated photodiodes etc.

The spindle of motor 11 carries a disc 12 which is formed with an annular graticule 13. The graticule co-operates with a photocell 14 and an associated light source 15 in a known manner to produce signal pulses which are indicative of the progress of the rotation of turntable member 6. Photocell 14 and the light source 15 are mounted on respective brackets 16 and 17 which are secured to a main frame 18 for the apparatus which frame also supports the motor 11. It will be appreciated that the turntable member 6 will also require support and location and this is provided by suitable idler wheels 19, 20, 21 and 22 mounted on the frame 18. The form of the frame 18 is not of the essence of this invention and it is shown in the particular form of Figure 1 for the purposes of example only.

The source 8 includes an elongated target/anode structure 23, an electron gun 24, which produces a beam 25 of electrons, and deflection plates 26, although deflection coils could equally well be used. Two extreme source positions 27a and 27c are shown in Figure 1, from which it can be seen that, in any source posi-

tion, a fan of radiation is directed at the body 1. It can also be seen that the detector array 9 takes no part in the lateral movement, this array being of sufficient breadth to accommodate the scanning of the radiation.

It will be appreciated that some detectors, for example the one shown at 28, need to be capable of receiving radiation from a number of different directions, for example as shown by the beams 29 and 30 which relate to source positions 27a and 27c respectively. This would cause difficulties, as mentioned previously, if the detectors were collimated and so, in this example, no collimators are used and the effects of scatter are allowed for by suitable computation as will be made clear later.

The output signal pulses derived from the photocell 14 are applied to a timing pulse shaping circuit 31, which also receives start and stop command pulses from a remote control switch 32. The shaped pulses from circuit 31 are fed to a timing circuit 33 which is arranged to generate deflection waveforms for application to the deflection plates 26 of tube 8 so that the lateral scanning of the radiation is suitably synchronised with the rotation of turntable member 15, in accordance with a desired inter-relationship between the lateral and rotational scanning movements. Suitable inter-relationship between the two scanning movements are described in the aforementioned British Patent Specification No. 1,529,799 and British Patent Application No. 43,984/75 (Serial No. 1,558,062) and, as such inter-relationships are not essential to the understanding of this invention, they will not be further described herein.

The signals provided by the detector array 9 during the scanning are converted into discrete signals indicative of the amounts of radiation emergent from the body along respective, substantially linear paths, by causing the detectors to feed respective integrator circuits which are read and reset periodically under the influence of the timing pulses derived from the photocell unit 14. These discrete signals are digitised, converted to logarithmic form, and processed in any convenient manner, such as that described in the aforementioned British Patent Specification No. 1,283,915 or that described in British Patent Specification No. 1,471,531; allowance being made for the fact that the beam paths followed by the radiation through the body will not be strictly linear because of the effects of the steady rotation of turntable member 6.

Referring now to Figure 2, the processing arrangements utilised in accordance with this example of the invention will be described in more detail. Each detector in the array 9 feeds a respective pre-processing circuit 34; only the circuit 34 for the k'th detector being shown in Figure 2. Each circuit 34 includes an amplifier 35, an integrator 36 which, as mentioned previously, is periodically read and reset by

timing pulses derived from the photocell unit 14, an analogue-to-digital convertor circuit 37 and a logarithmic convertor circuit 38. All of the pre-processing circuits 34 feed a common parallel set sorting circuit 39 which is effective in the manner disclosed in British Patent Specification No. 1,493,594 to sort the output signals, which are commonly referred to as "edge values", into sets relating to substantially parallel beam paths through the body. The sorted edge values are applied, parallel set after parallel set, to a processing circuit 40 of the kind described in the aforementioned British Patent Specification No. 1,471,531. Alternatively, the processing arrangements disclosed in British Patent Specification No. 1,283,915 can be used, in which case the circuit 39 is not required.

The circuit 40 is effective to evaluate, from the edge value data applied thereto, an absorption coefficient for each of many elemental areas distributed over the irradiated cross-sectional slice of the body. If the detectors 9 had been suitably collimated, this evaluation would have been the final step in the examination, but since the detectors are not collimated, further processing is required to reduce or eliminate the effects of scatter. This further processing involves the components 41 through 46, which will now be described in more detail.

The evaluated coefficients are applied to a random access digital store 41 which contains a storage location for each of the aforementioned elemental areas. Typically the areas are notionally delineated in the form of a rectangular matrix in the irradiated slice of the body, and it is desirable that the storage locations of store 41 be arranged in similar format.

In order to compensate the evaluated coefficients for the effects of scatter, each elemental area must be considered as a potential scattering centre for each beam path which intersects it. It is clear that it is necessary to ascertain the effects of scatter for any beam path and elemental area only for edge values which are obtained at the same time as the edge value relating to the beam path in question. An address selector 42 is arranged to designate the linear (or substantially linear) combination of elemental areas intersected by a first beam path. It also designates a first elemental area on said first beam path. The interconnection of address selector 42 with the digital store 41 is such that, once the first beam path and elemental area in question have been designated by selector 42, the coefficients evaluated for all other elemental areas intersected by the said first beam path from the irradiated side of the body up to said first designated elemental area are applied, in any sequence, to a summing circuit 44 which thereby evaluates the absorption likely to have been suffered by the radiation on traversing said first beam path through said body as far as

said first designated elemental area. This evaluated absorption is applied to a multiplying circuit 45, and the evaluated absorption coefficient for the first designated elemental area is also applied to circuit 45 from store 41 in response to a signal applied thereto from the address selector 42. These two values when multiplied together provide an indication of the amount of scattered radiation likely to have been produced by the projection of radiation through said first designated elemental area along said first designated beam path. This scatter value is assumed to be isotropic, and thus has to be subtracted from the other edge values which were derived at the same time as the edge value relating to said first designated beam path. The aforementioned subtraction is effected by means of a subtraction circuit 46, to which the output signals from circuit 45 are applied, and a second digital store 43 which is arranged to store all the edge values in the order in which they were derived. In response to signals from the address selector 42, store 43 applies, in sequence, to circuit 46 all the edge values, apart from the one relating to said first designated beam path, which relate to beam paths irradiated at the same time as said first designated beam path. The corrected edge values are re-inserted in the appropriate locations of store 43, and the address selector circuits are then arranged to designate a second elemental area on said first beam path. The above process is repeated until all elemental areas along the first beam path have been dealt with, and a second beam path is then designated. The procedure is repeated until all combinations of beam paths and elemental areas have been dealt with, at which time the store 43 holds a complete set of scatter compensated edge values. These compensated edge values are then applied, via circuit 39, to the processing circuit 40 and an improved evaluation of the various absorption coefficients, duly compensated for scatter, is produced.

The above sequence of events can, of course be repeated if desired in order to successively approximate the true values for the coefficients.

All of the functions performed by the components 39 to 46 inclusive are carried out under the control of a master timing circuit 47, as indicated by the respective interconnections, shown in dashed lines for clarity, between the circuit 47 and the components 39 to 46. Circuit 47 receives input information from unit 14 and circuit 33 and this enables the derivation of the data to be accurately monitored, so that all beam paths can be properly identified.

WHAT WE CLAIM IS:—

1. Radiographic apparatus including a source of penetrating radiation, such as X-radiation, arranged to project radiation through a cross-sectional slice of a body, detector means disposed to receive radiation emergent from the body and processing means for operating on



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timing pulses derived from the photocell unit 14, an analogue-to-digital convertor circuit 37 and a logarithmic convertor circuit 38. All of the pre-processing circuits 34 feed a common parallel set sorting circuit 39 which is effective in the manner disclosed in British Patent Specification No. 1,493,594 to sort the output signals, which are commonly referred to as "edge values", into sets relating to substantially parallel beam paths through the body. The sorted edge values are applied, parallel set after parallel set, to a processing circuit 40 of the kind described in the aforementioned British Patent Specification No. 1,471,531. Alternatively, the processing arrangements disclosed in British Patent Specification No. 1,283,915 can be used, in which case the circuit 39 is not required.

The circuit 40 is effective to evaluate, from the edge value data applied thereto, an absorption coefficient for each of many elemental areas distributed over the irradiated cross-sectional slice of the body. If the detectors 9 had been suitably collimated, this evaluation would have been the final step in the examination, but since the detectors are not collimated, further processing is required to reduce or eliminate the effects of scatter. This further processing involves the components 41 through 46, which will now be described in more detail.

The evaluated coefficients are applied to a random access digital store 41 which contains a storage location for each of the aforementioned elemental areas. Typically the areas are notionally delineated in the form of a rectangular matrix in the irradiated slice of the body, and it is desirable that the storage locations of store 41 be arranged in similar format.

In order to compensate the evaluated coefficients for the effects of scatter, each elemental area must be considered as a potential scattering centre for each beam path which intersects it. It is clear that it is necessary to ascertain the effects of scatter for any beam path and elemental area only for edge values which are obtained at the same time as the edge value relating to the beam path in question. An address selector 42 is arranged to designate the linear (or substantially linear) combination of elemental areas intersected by a first beam path. It also designates a first elemental area on said first beam path. The interconnection of address selector 42 with the digital store 41 is such that, once the first beam path and elemental area in question have been designated by selector 42, the coefficients evaluated for all other elemental areas intersected by the said first beam path from the irradiated side of the body up to said first designated elemental area are applied, in any sequence, to a summing circuit 44 which thereby evaluates the absorption likely to have been suffered by the radiation on traversing said first beam path through said body as far as

said first designated elemental area. This evaluated absorption is applied to a multiplying circuit 45, and the evaluated absorption coefficient for the first designated elemental area is also applied to circuit 45 from store 41 in response to a signal applied thereto from the address selector 42. These two values when multiplied together provide an indication of the amount of scattered radiation likely to have been produced by the projection of radiation through said first designated elemental area along said first designated beam path. This scatter value is assumed to be isotropic, and thus has to be subtracted from the other edge values which were derived at the same time as the edge value relating to said first designated beam path. The aforementioned subtraction is effected by means of a subtraction circuit 46, to which the output signals from circuit 45 are applied, and a second digital store 43 which is arranged to store all the edge values in the order in which they were derived. In response to signals from the address selector 42, store 43 applies, in sequence, to circuit 46 all the edge values, apart from the one relating to said first designated beam path, which relate to beam paths irradiated at the same time as said first designated beam path. The corrected edge values are re-inserted in the appropriate locations of store 43, and the address selector circuits are then arranged to designate a second elemental area on said first beam path. The above process is repeated until all elemental areas along the first beam path have been dealt with, and a second beam path is then designated. The procedure is repeated until all combinations of beam paths and elemental areas have been dealt with, at which time the store 43 holds a complete set of scatter compensated edge values. These compensated edge values are then applied, via circuit 39, to the processing circuit 40 and an improved evaluation of the various absorption coefficients, duly compensated for scatter, is produced.

The above sequence of events can, of course be repeated if desired in order to successively approximate the true values for the coefficients.

All of the functions performed by the components 39 to 46 inclusive are carried out under the control of a master timing circuit 47, as indicated by the respective interconnections, shown in dashed lines for clarity, between the circuit 47 and the components 39 to 46. Circuit 47 receives input information from unit 14 and circuit 33 and this enables the derivation of the data to be accurately monitored, so that all beam paths can be properly identified.

WHAT WE CLAIM IS:—

1. Radiographic apparatus including a source of penetrating radiation, such as X-radiation, arranged to project radiation through a cross-sectional slice of a body, detector means disposed to receive radiation emergent from the body and processing means for operating on

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output signals, provided by said detector means and indicative of the absorption suffered by said radiation on traversing substantially linear paths through said slice, to evaluate absorption coefficients for a plurality of elemental areas distributed over said slice, said processing means including compensating means for adjusting said evaluated coefficients to allow for the detection, by said detector means, of scattered radiation.

2. Apparatus according to Claim 1 wherein said compensating means comprises means for deriving a respective scatter adjustment signal for the elemental areas intersected by the path giving rise to a given output signal, and means for correlating the scatter adjustment signals relating to said given output signal with other output signals obtained at substantially the same time as said given output signal to compensate said other output signals for scatter due to matter disposed at the said elemental areas along the beam path to which said given output signal relates.

3. Apparatus according to Claim 2 including a store for said evaluated coefficients, and wherein said means for deriving comprises means for summing the stored coefficients relating to elemental areas traversed by the radiation to reach a given one of said elemental areas along said beam path to which said given output signal relates, and means for multiplying the sum signal by the evaluated coefficient stored for said given area to produce the scatter adjustment signal in respect of said given area.

4. Apparatus according to either Claim 2 or 3 wherein said means for correlating comprises a subtraction circuit arranged to subtract, from each of said other output signals, the scatter adjustment signal for each area along said path to which said given output signal relates, to produce scatter compensated output signals.

5. Apparatus according to any preceding claim including means for designating each output signal in turn as said given output signal to produce modified output signals each corrected by multiple scatter adjustments.

6. Apparatus according to Claim 5 including means for processing said modified output signals to evaluate scatter compensated absorption coefficients for said elemental areas.

7. Apparatus according to Claim 6 wherein said means for processing said modified output signals and said processing means for operating on said first mentioned output signals operate in accordance with a common mathematical procedure.

8. Apparatus according to Claim 7 wherein said means for processing said modified output signals and said processing means for operating upon said first mentioned output signals are constituted by a common processing means.

9. Radiographic apparatus for examining a cross-sectional slice of a patient, the apparatus comprising source means for projecting X-radiation along a group of beam paths across said slice, means for scanning the source means around the patient so that the source means projects radiation across said slice along further groups of beam paths, means for producing electrical signals, each indicative of the amount of X-radiation emergent from the patient along a respective one of said beam paths, means for processing said electrical signals to evaluate respective absorption signals representing the absorption of the X-radiation at each of many elements distributed over the slice, said absorption signals being liable to errors due to the interaction of some at least of said elements with the X-radiation, means for deriving, from said absorption signals, correction factors indicative of said errors, means for modifying said electrical signals in response to said correction factors, means for processing the modified electrical signals to evaluate further absorption signals for said elements, said further absorption signals being corrected, at least in part, compared with said first-mentioned absorption signals, for said errors, and means for utilising said further absorption signals to generate a visual representation of the slice of patient.

10. Radiographic apparatus substantially as herein described with reference to the drawings filed with the Provisional Specification.

11. A method of examining a cross-sectional slice of a body by means of penetrating radiation such as X-radiation including the steps of:—

(a) obtaining electrical signals indicative of the absorption suffered by said radiation on traversing each path of a plurality of sets of substantially linear paths through said slice,

(b) processing said electrical signals to provide values of the absorption coefficient, with respect to said radiation, at each of a plurality of locations distributed over said slice,

(c) evaluating for each location and for each path passing therethrough, a scatter signal indicative of the extent to which each location scatters radiation incident thereon along each said path traversing it,

(d) modifying each electrical signal by subtracting therefrom the scatter signals evaluated in respect of all locations traversed by other paths irradiated at the same time as the path to which the signal being modified relates, and

(e) processing, by the same technique as was used in step (b), the modified signals to provide scatter compensated values of absorption coefficient for said locations.

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