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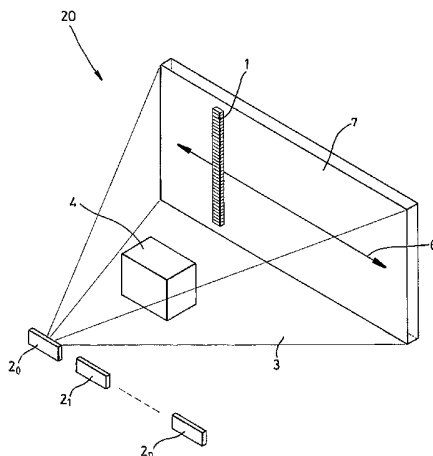
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(54) Title: X-RAY SCREENING APPARATUS



(57) Abstract: An x-ray screening apparatus having particular use in examining and inspecting luggage and baggage in airport environments is described, the screening apparatus comprising at least one x-ray source, at least one x-ray detector and a sampling volume, e.g. luggage, disposed between the source and the detector. The apparatus is configured such that the at least one detector is able to receive radiation from the at least one source, which radiation has passed through each spatially resolvable volume element within the sampling volume at at least two different angles of incidence, and in which at least two of the source, detector and sampling volume are relatively displaceable so as to enable fully independent relative displacement of each of the source, detector and sampling volume. Interpretation of the detected radiation allows stereoscopic images of the sampling volume to be constructed, providing depth information relating to items within the sampling volume.



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X-RAY SCREENING APPARATUS

The present invention relates to x-ray screening apparatus and x-ray imaging systems, and in particular relates to a portable x-ray apparatus for examining the
5 contents of objects.

X-ray imaging techniques are widely used to examine the contents of objects and to inspect materials having layered structures, due to the penetrative energy of x-rays and the inherent transmissivity of most materials to x-rays.

10

The basic principle of operation is illustrated in figure 1, where a static x-ray detector 1 and static x-ray source 2 are oppositely disposed on either side of a moving object 4, which is typically mechanically driven transversely across the axis separating the detector 1 and source 2 (shown by the arrow 5). The interaction
15 of the object 4 with the x-ray slit beam from source 2, attenuates the energy within the beam, such that the energy incident on the detector 1 forms a shadowgraph which is representative of each spatially resolvable volume element within the object through which the beam has passed.

20 Instead of mechanically driving the object 4 through a slit beam of x-rays, the object 4 can remain at rest and the x-ray source 2 can be adapted to produce a cone of x-ray emission which is sufficiently wide so as to completely irradiate the object 4, as shown in figure 2. The detector 1 may then be mechanically driven transversely across the cone of radiation (as shown by arrow 6) within the
25 enclosure 7.

However, a drawback of both of these arrangements is that the shadowgraph provides no depth information relating to the location of items within the object 4. Therefore, an operator cannot derive any details concerning how far inside the
30 object particular items actually reside.

In airport environments, the inspection of baggage and luggage is an important activity in maintaining the safety of both passengers and aircrew.

Hence, there is a need to derive as much information as possible concerning the contents of passengers' luggage. Depth information can be a key diagnostic in assessing whether an item is potentially dangerous and/or illegal, and therefore
5 some x-ray screening devices have incorporated the use of two static detectors which are spatially separated so as to receive radiation from a static source along two different angular directions. In this way, an object can be driven between the stationary apparatus and be imaged from two different viewpoints, such that limited depth information may be derived.

10

However, such apparatus tend to be large, bulky and non-portable, and often require mechanical drive systems, such as conveyor belts, so as to drive the object during the imaging process. Moreover, since only two different viewpoints are obtained per object, it is not always possible to derive sufficient additional
15 information, concerning the whereabouts of items, over that of single shadowgraph imaging.

20

Other techniques of x-ray imaging can provide depth information relating to the contents of objects, however most of these do not particularly lend themselves to screening apparatus for use in airport environments.

25

For example, x-ray laminography and tomosynthesis are non-destructive radiographic techniques whereby individual layers of a 3-dimensional object can be inspected one at a time. The principle of x-ray laminography relies on the
25 synchronised motion of any two of the x-ray source, detector and object, to form a geometric focus plane corresponding to a particular slice in the object. In typical systems, the object remains at rest while the source and detector are moved in a synchronised manner around the object. Images are collected continuously throughout the synchronised motion and are then averaged together to form a final
30 image. Items that are in the focal plane are always projected to the same point on the detector, so that these items appear prominent in the final image, while items that are out of the focal plane, are blurred out of the image by averaging, so these items appear only faintly.

Digital x-ray laminographic techniques allow all layers of an object to be imaged at the same time, as the projections can be reconstructed using computer processing techniques which can co-register particular features in multiple images
5 so as to select the desired focal plane. In this way, each layer of the object can be inspected as desired, permitting a 3-dimensional model of the object to be constructed. A technique of image co-registration in relation to x-ray laminography is discussed in US5583904.

10 A drawback of x-ray laminographic and tomosynthesis techniques is that they typically require complex and expensive drive mechanisms and control circuitry, so as to achieve the required synchronised motion of any two of the source, detector and object. Moreover, due to the synchronised motion, such techniques tend to be relatively slow, and therefore have only a limited speed of inspection.

15 The present invention is directed to an x-ray screening apparatus in which two or more of the source, detector and sampling volume, in which an object resides, are relatively displaceable, such that complex drive mechanisms and associated control circuitry are not required to invoke synchronised or coordinated motion.
20 Instead, the x-ray screening apparatus can be adapted to automatically determine the relative displacement and/or orientation of the source and detector with respect to each other, so that the particular configuration of the source and detector can be determined during image capture.

25 Moreover, the x-ray screening apparatus of the present invention is able to provide depth information concerning items within an object under inspection by constructing stereoscopic images for viewing by an operator. Therefore, the present invention is particularly suited for airport environments, or other locations, where inspection of baggage, luggage or other personal items is required, e.g. at
30 check-in points in government and military buildings etc.

An object of the present invention is to provide a portable x-ray screening apparatus which can produce stereoscopic images of a sampling volume which is at rest during inspection.

- 5 Another object of the present invention is to provide an x-ray screening apparatus which can produce stereoscopic images of a sampling volume under inspection by enabling fully independent relative displacement of each of the x-ray source, x-ray detector and the sampling volume.
- 10 Another object of the present invention is to provide an x-ray screening apparatus which can produce stereoscopic images of a sampling volume under inspection by using at least two x-ray sources and a detector which are relatively displaceable along an axis that is transverse to the axis of separation of the sources and detector.
- 15 Another object of the present invention is to provide an x-ray screening apparatus which can provide depth information relating to items within the sampling volume under inspection.
- 20 Another object of the present invention is to provide an x-ray screening apparatus which can automatically determine the relative displacement and/or orientation of a source and a detector which are independently displaceable with respect to each other.
- 25 Some or all of the above objects may be achieved by various embodiments of the invention as described herein.

According to a first aspect of the present invention there is provided an x-ray screening apparatus, comprising:

- 30 at least one x-ray source;
 at least one x-ray detector; and
 a sampling volume disposed between the source and the detector;

the apparatus being configured such that the at least one detector is able to receive radiation from the at least one source which radiation has passed through each spatially resolvable volume element within the sampling volume at at least two different angles of incidence, and

- 5 in which at least two of the source, detector and sampling volume are relatively displaceable so as to enable fully independent relative displacement of each of the source, detector and sampling volume.

According to a second aspect of the present invention there is provided an x-ray
10 screening apparatus, comprising:

at least two spatially separated x-ray sources;

at least one x-ray detector;

a sampling volume disposed between the sources and the detector;

the apparatus being configured such that the at least one detector is able to
15 receive radiation from the at least two sources which radiation has passed through each spatially resolvable volume element within the sampling volume at at least two different angles of incidence, and

in which the sources and detector are relatively displaceable along an axis that is transverse to the axis of separation of the sources and detector.

20

According to a third aspect of the present invention there is provided an x-ray screening apparatus, comprising:

at least one x-ray source;

at least one x-ray detector; and

25 a sampling volume disposed between the source and the detector;

the apparatus being configured such that the source and detector are able to move independently of each other, and

further comprising means associated with at least one of the source and the detector adapted to automatically determine the relative displacement and/or
30 orientation of the source and detector with respect to each other.

Embodiments of the present invention will now be described in detail by way of example and with reference to the accompanying drawings in which:

Figure 1 is a perspective view of a conventional x-ray screening apparatus in which an object is passed through an x-ray slit beam.

5 Figure 2 is a perspective view of another conventional x-ray screening apparatus in which a detector scans across a cone of x-ray radiation.

Figure 3 is a perspective view of a preferred arrangement of the x-ray screening apparatus of the present invention.

10 Figure 4 is a perspective view of another preferred arrangement of the present x-ray screening apparatus.

Figure 5 shows the x-ray screening apparatus of figure 3 with a detector arrangement for use with the present invention.

Figures 6 and 7 are perspective views of other detector arrangements for use with the present x-ray screening apparatus.

15 Figure 8 is a perspective view of preferred detector arrangement according to the present invention.

Figure 9 is a schematic perspective view of a preferred arrangement of the present x-ray screening apparatus.

20 With reference to figure 3 there is shown a particularly preferred arrangement of an x-ray screening apparatus according to the present invention. The screening apparatus 20 comprises at least one x-ray source 2₀ and at least one x-ray detector 1 arranged on substantially opposing sides of a sampling volume 4, such that the sampling volume 4 is disposed between the source 2₀ and detector 1 so as to
25 receive x-ray radiation from the source 2₀.

The x-ray source and x-ray detector may be any suitable conventional devices, adapted for use with the present x-ray screening apparatus as prescribed in the following arrangements.

30

The sampling volume is a space suitable for receiving objects for inspection which have at least a partial inherent transmissivity to x-ray radiation. In airport environments etc., the objects would typically be baggage and luggage or other

personal belongings, which are associated with passengers and aircrew. However, it is to be appreciated that the objects could be any type of object in which the contents (herein referred to “items”) need to be inspected and identified.

- 5 In accordance with particularly preferred arrangements of the present invention, the sampling volume 4 (and therefore any objects therein) remains at rest during the screening process. Herein references to a “screening process” are to be taken as corresponding to a single or multiple imaging cycle of the sampling volume, in which two or more images of the sampling volume are obtained per imaging cycle
10 by the detector 1. In other embodiments, the sampling volume may be ‘moved’, i.e. any objects therein are moved, by provision of a suitable conveyor or the like.

To obtain depth information relating to the items within the sampling volume 4, it is necessary to obtain at least two images of each spatially resolvable volume
15 element within the sampling volume 4 taken from two different angles. In this way, it is possible to construct a stereoscopic image of the sampling volume 4 based on the relative positions of corresponding features within the different images. Since the images are taken from different angles, corresponding features will undergo an angular (i.e. parallax) shift relative to background features in
20 the images.

By “spatially resolvable volume element” we mean the smallest physical volume discernable within the sampling volume 4. It is to be appreciated that this quantity is dependent on the resolution of the screening apparatus, which in turn is
25 governed by the resolution of the x-ray detector 1.

In preferred arrangements, the technique of imaging the sampling volume 4 at at least two different angles is achieved by having the source 2₀ and detector 1 mounted in such a way, that each is relatively displaceable with respect to the
30 other. Preferably, the sampling volume 4 (i.e. any objects within it) remains at rest during the screening process, and the source 2₀ and detector 1 are then moved relative to the sampling volume 4 and each other. To achieve the required angular shift of features within the different images of the sampling volume 4, the source

2₀ and detector 1 are displaced relative to the sampling volume, such that the radiation is made to pass through each spatially resolvable element within the sampling volume at at least two different angles of incidence.

- 5 As shown in figure 3, the source 2₀ may be moved along an axis that is substantially transverse to the axis of separation of the source 2₀ and detector 1. This feature is represented in figure 3 by sources 2₀ to 2_n, in which each labelled source indicates a position that may be assumed during the screening process relative to the sampling volume 4. It is to be appreciated that the positions shown
10 are illustrative only and are not intended to be limiting, and consequently any suitable position may be adopted by the source 2₀ during the screening process.

- The source is adapted to preferably emit a cone of x-ray radiation 3, as shown in figure 3, which preferably has an angular extent (i.e. width and height) at the
15 position of the sampling volume 4 that is sufficient to completely irradiate the sampling volume 4. By "cone" we mean a geometric volume that is substantially conical, pyramidal or tetrahedral in form, whether symmetrical or not. However, it is to be appreciated that any suitable emission volume may be used.

- 20 Referring again to figure 3, it is clear therefore that as the source 2₀ moves relative to the sampling volume 4, the cone of x-ray radiation 3 is displaced accordingly, however for clarity, the radiation cones at the positions of sources 2₁ to 2_n have not been shown.

- 25 In preferred arrangements, the detector 1 is mounted so as to be able to move along an axis that is transverse to the axis of separation of the source 2₀ and detector 1. However, so as to avoid the need for complex mechanical drive mechanisms, this motion need not be synchronised with motion of the source 2₀. The detector 1 sweeps across the radiation cone 3 of the source (indicated by
30 arrow 6 in figure 3), moving relatively to the sampling volume 4 and source 2₀, and detects the radiation that has passed through each spatially resolvable volume element within the sampling volume 4. On each sweep, the detector 1 captures a shadowgraph image of the sampling volume 4, as determined by the particular

relative configuration of source 2₀, sampling volume 4 and detector 1 at the time of the sweep. The detector 1 need only obtain one image for each particular configuration, or alternatively multiple images can be obtained depending on the application.

5

Not until the source 2₀, sampling volume 4 and detector 1 assume a subsequent relative configuration however, can depth information begin to be derived from the captured images.

10 It is to be appreciated that a “detector sweep” corresponds to a physical pass of the detector 1 through the radiation cone 3 of the source 2₀ in either azimuthal direction, and therefore “detector sweeps” are to be construed accordingly.

In preferred arrangements, the detector 1 is a 1-dimensional array of x-ray
15 sensitive elements arranged so that the vertical axis of the array is substantially orthogonal to the direction of motion of the array, as shown in figure 3. It is to be appreciated therefore, that the detector only receives radiation from a source along a plane aligned with the vertical axis of the array. Hence, from the detector’s point of view, the source effectively corresponds to a slit beam source, as typically used
20 in conventional x-ray screening apparatus, as shown in figure 1.

In alternative preferred arrangements, the source 2₀ may remain at rest and the sampling volume 4 and detector 1 may be displaced relative to each other and the source 2₀. Alternatively, the detector 1 may remain at rest and the source 2₀ and
25 sampling volume 4 may be displaced relative to the detector 1. By displacement of the sampling volume, we mean displacement of any objects therein.

Hence, it is to be appreciated that in accordance with the present invention, any of at least two of the source 2₀, detector 1 and sampling volume 4 are relatively
30 displaceable, such that the screening apparatus 20 enables fully independent relative displacement of each of the source 2₀, detector 1 and sampling volume 4, i.e. without requiring corresponding synchronised motion of the others.

The source 2₀, detector 1 and sampling volume 4 can be moved in any desired pattern of coordinated motion, but the individual motions of the components do not need to be synchronised. In preferred arrangements, at least one of the source 2₀, detector 1 and sampling volume 4 are adapted to move in a linear or arcuate
5 motion.

In preferred arrangements, the sampling volume remains at rest, however each one of the source 2₀ and the detector 1 has an associated drive mechanism, which is operable to displace the source 2₀ and detector 1 relative to each other and to the
10 sampling volume 4. However, in arrangements in which the sampling volume 4 is moved (and one of the others is at rest), this too has an associated drive mechanism.

The drive mechanisms are preferably configured so as to permit independent
15 movement of any of the source 2₀, detector 1 and sampling volume 4.

In preferred arrangements, the source 2₀ is adapted to operate over a variable range of x-ray energies or at a plurality of discrete x-ray energies. The use of variable or discrete x-ray energies provides a useful diagnostic tool in
20 discriminating between materials of items within the sampling volume 4, as, for example, the x-ray transmissivity of organic materials is inherently different to that of metallic and other materials.

Therefore, by interpreting the shadowgraph images obtained at different x-ray
25 energies, material/compositional data can be determined, which is particularly useful in assessing the nature of items within the sampling volume 4. Hence, the x-ray screening apparatus 20 of the present invention can not only provide depth information in respect of items within the sampling volume 4, but also additionally discriminate between different materials.

30

The source x-ray energies can be varied during a particular imaging cycle, or else can be varied after each imaging cycle, depending on the desired application and nature of the sampling volume 4 under inspection.

Referring to figure 4, there is shown another particularly preferred arrangement of the x-ray screening apparatus 20 of the present invention. In this arrangement, the x-ray source corresponds to a source assembly 2, which is a mounting or housing
5 that remains physically at rest during the screening process. However, to achieve a displacement of the source relative to the sampling volume 4 and the detector 1, the source assembly 2 comprises a plurality of spatially separated emission sites 11_0 to 11_n on an outwardly facing surface of the assembly, each site effectively corresponding to an individual x-ray source and operable to emit radiation
10 independently of the other sites.

Each emission site $11_0...11_n$ on the source assembly 2 may be formed by a respective collimation device, or alternatively by some other suitable mechanical slit and shielding arrangement etc.

15 Preferably, the emission sites $11_0...11_n$ are disposed along an axis that is substantially transverse to the axis of separation of the source and detector, as shown in figure 4. To effect relative motion of the source, each emission site $11_0...11_n$ can be configured to emit radiation as part of an ordered sequence of
20 emission, e.g. one-after-another along the axis, which is preferably coordinated with sweeps of the detector 1 during the screening process.

It is to be appreciated that the order in which the emission sites $11_0...11_n$ are switched to emit radiation, is to some degree dependent on the position of the
25 detector 1 relative to the source and sampling volume 4, as the detector 1 must be able to sweep across the radiation cone of the switched emission site so as to detect the radiation.

The ordered sequence of emission is preferably cyclic, with images of the
30 sampling volume 4 being obtained by virtue of radiation emitted by whichever emission site is active at the time of the particular detector sweep.

The emission sites $11_0 \dots 11_n$ are preferably adapted to emit a cone of x-ray radiation 3, in the manner of the other preferred arrangements. As shown in figure 4, the radiation cone 3 of emission site 11_0 is preferably of a sufficient angular extent at the position of the sampling volume, so as to completely irradiate the sampling volume 4. For clarity, the radiation cones of emission sites 11_1 to 11_n have not been shown, but it is to be appreciated that the cones would be displaced as the emission sites $11_0 \dots 11_n$ are sequentially switched on and off.

The detector 1 may then sweep across the respective radiation cones 3, so as to obtain images of the sampling volume 4 at different angles.

In accordance with other preferred arrangements, the emission sites $11_0 \dots 11_n$ may be adapted to emit a variable range of x-ray energies or else emit discrete x-ray energies, so as to derive material/compositional data concerning the contents of the sampling volume 4.

In accordance with the preferred arrangement of figure 4, it is clear that the emission sites $11_0 \dots 11_n$ (recalling that these act as individual sources) and detector 1 are relatively displaceable along an axis that is transverse to the axis of separation of the sources and detector. Therefore, no complex mechanical drive mechanisms are required to achieve synchronised motion of the emission sites and detector.

Referring now to figure 5, there is shown a particular arrangement of the detector for use with the present x-ray screening apparatus 20. In this arrangement, the detector includes a plurality of 1-dimensional arrays $1_0 \dots 1_n$ of x-ray sensitive elements, arranged one-in-front-of-the-other, along a line of sight between the source 2_0 and detector. Although the source 2_0 is shown as being displaceable at positions represented by sources 2_0 to 2_n , it is to be appreciated that this detector arrangement can be used with the source assembly of the other preferred arrangements.

By “x-ray sensitive element” we mean a detector element that is capable of detecting x-ray radiation, so as to produce a corresponding discernable signal or other indicator in response to the x-ray radiation. Any suitable x-ray detector element may be used with the x-ray screening apparatus of the present invention, including, but not limited to, semiconductors, high-energy counters and phosphor/scintillation-based devices.

In arranging the 1-dimensional arrays $1_0 \dots 1_n$ in the manner as shown in figure 5, additional x-ray energy information can be derived, as depending of the number n of arrays used, particular energy bands can be selected for imaging purposes, which again can be useful in assessing which materials, or types of material, are present in the sampling volume 4 under inspection. Depending on the particular application, optimisation of the x-ray energy band can be a useful technique in tailoring the present screening apparatus 20 to identify specific materials or types of material. This feature could be particularly important in airport environments and security check-in points, where typically the identification of metallic objects (e.g. weaponry) is a primary concern.

Other techniques of optimising the x-ray energy band information for use with the present x-ray screening apparatus are illustrated in figures 6 and 7. In figure 6, the x-ray sensitive elements of the array 1 are arranged in an alternating pattern of varying thickness (see inset 8), while instead, or in addition, a conventional x-ray absorbent layer (e.g. copper) may be associated with the array, as shown in figure 7, such that the layer is co-located with the alternating pattern of x-ray sensitive elements (see inset 9).

It is to be appreciated that any suitable technique of optimising the x-ray energy band information may be used with the x-ray screening apparatus 20 of the present invention.

Referring to figure 8, there is shown a preferred arrangement of the detector according to the present invention, which is consistent with each of the previously described arrangements. In this arrangement, the detector is preferably a single x-

ray sensitive element 10, which is mounted to a drive mechanism that permits the element 10 to be moved in at least two degrees of freedom, such that motion is possible along at least two mutually orthogonal axes. As shown in figure 8, the detector may then perform a sweep of the radiation cone 3 (not shown), by being
5 mechanically driven in azimuth (shown by arrow 6L) and altitude (shown by arrow 6V), thereby effectively performing the same detector sweep as a 1-dimensional array.

It is to be appreciated that this technique need not be limited to only a single
10 element 10, and that more than one element may be driven in this manner, in accordance with the present invention.

The present invention is intended to resolve the problems of the art, in that complex mechanical drive mechanisms are not required, since synchronised
15 motion of the source 2₀ and detector 1, or detector 1 and object 4, as mandated by laminographic and tomosynthesis techniques is not required. Instead, the motion of the source 2₀ and detector 1 is greatly simplified, since although a degree of coordinated positioning of the source 2₀, detector 1 and sampling volume 4 is required, each of these components can be moved independently of the others, so
20 that all of the components are relatively displaceable.

Moreover, as the sampling volume 4 preferably remains at rest during the screening process, no mechanical driving system is required to manipulate the physical position of the sampling volume. As a consequence the present apparatus
25 can be fabricated as a portable unit, such that the detector 1 and source 2₀ preferably are in the form of two separately deployable components. This is particularly advantageous for screening suspicious packages or objects in situ where the object should not be moved.

30 In preferred arrangements, as shown in figure 9, the detector 1 is integral with, or contained within, a detection head assembly 30 (also schematically represented as 7 in figures 3 to 5 and 8). The head assembly 30 may be mounted on an adjustable stand 31 or support structure, which permits the height of the head assembly to be

adjusted relative to a floor level 50. The head assembly 30 preferably includes a mechanical drive mechanism 32 which is operable to impart motion of the detector 1, as described in relation to the foregoing arrangements. The drive mechanism 32 may be any suitable drive device or motorised bearing etc., which
5 is capable of moving the detector relative to the sampling volume 4 and the source 2₀.

In like manner, the source 2₀ is preferably mounted within a source assembly 2, which has a corresponding adjustable stand 33 or support structure, which permits
10 the height of the source assembly to be adjusted relative to the floor level 50. The source assembly 2 preferably includes a mechanical drive mechanism 34 which is operable to impart motion of the source 2₀. The drive mechanism 34 may be any suitable drive device or motorised bearing etc., which is capable of moving the source 2₀ relative to the sampling volume 4 and the detector 1.

15

It is to be appreciated that, in preferred arrangements in which the source 2₀ remains at rest, the source assembly 2 need not be driven, therefore the drive mechanism 34 is either removed or deactivated.

20 During use therefore, the x-ray screening apparatus 20 of the present invention, can be readily positioned with respect to a sampling volume 4 and objects therein, which may be at rest on a floor surface 50, or else residing on an intermediary platform (not shown), such as a table etc. The head assembly 30 may be positioned on one side of the sampling volume, while the source assembly 2 is
25 positioned substantially on the other side.

In accordance with the present invention, the x-ray screening apparatus 20 further comprises a control unit 40, which is preferably remotely located from the detection head and source assemblies 30, 2. The control unit 40 is coupled to the
30 detector 1 in the detection head assembly 30, to receive data from the detector 1 corresponding to the detected radiation. The control unit 40 is preferably further coupled to the source assembly 2 so as to control the emission of the radiation.

In preferred arrangements, the control unit 40 is a computing device, such as a desktop computer, laptop computer or even a hand-held portable device. Alternatively, the control unit can be a purpose built station, preferably remote from the detection head and source assemblies 30, 2.

5

The control unit is also preferably coupled to each of the drive mechanisms 32, 34 in the apparatus, such that the detector 1 and/or source 2₀ positions can be independently controlled via the control unit 40.

10 Preferably, the control unit 40 is coupled to at least one of the detection head assembly 30, source assembly 2 and drive mechanisms 32, 34 by wireless communications, such as, but not limited to, WiFi and Bluetooth. In preferred arrangements, the entire operation, including data retrieval and imaging, are all performed via wireless protocols.

15

Advantageously, the operator may then examine and inspect the contents of a plurality of objects without needing to be in the physical vicinity of the objects at the time of the screening process. Should any suspect items be identified within a particular object, appropriate personnel can be notified and the immediate vicinity
20 of the object can be evacuated, should this be deemed necessary.

Alternatively, the detection head and source assemblies 30, 2, along with the drive mechanisms 32, 34, may be coupled to the control unit 40 using hardwire connections.

25

The control unit 40 includes a processing means (not shown) which is preferably adapted to interpret the data received from the detector 1 during the imaging cycles, so as produce one or more images of the sampling volume under inspection.

30

An image processing algorithm, preferably implemented via software, interprets the received data so as to derive the angular shift information contained within the images. In this way, the processing means is able to construct a stereoscopic

representation of the sampling volume 4, which is preferably displayed as a image on an associated display monitor, or else is provided as a hardcopy.

Alternatively, the processing means can render the image for display on a suitable
5 virtual reality headset or other ocular viewing device, which is configured to permit an operator to virtually inspect different aspects of the sampling volume by movement of the operator's head.

In accordance with another aspect of the present invention, which may be
10 incorporated into any of the preceding arrangements, the x-ray screening apparatus 20 can be adapted to automatically determine the relative displacement and/or orientation of the source 2₀ and detector 1 with respect to each other. Advantageously, this is achieved without the need for a complex synchronised drive mechanism, thereby maintaining portability of the apparatus and ensuring
15 flexibility of deployment in screening environments.

In conventional screening apparatus, the positions of the source and detector are typically determined by encoders attached to the drive mechanism. The encoder information is provided to a control unit which is then recorded for use in
20 subsequent image reconstruction, allowing the exact orientation of the source and detector to be derived.

However, in accordance with the present invention, the relative displacement and/or orientation of the source 2₀ and detector 1 can be determined automatically,
25 without any reference to a drive mechanism or predetermined coordinate system. Instead, the head assemblies 30, 2 (discussed above in relation to figure 9) can simply be deployed at the screening site, in relation to the sampling volume 4, and the subsequent source and detector positions can be determined automatically either in real-time or during an image processing stage.

30 The ability to derive accurate source and detector positions is very important in reconstructing the captured image data, since in the case of stereoscopic images,

the precise viewing angles of the detector 1 relative to the source 2₀ must be known throughout the screening process.

According to a preferred arrangement, the displacement and/or orientation of the source 2₀ and detector 1 can be determined relative to each other by using one or more of several complementary techniques. Hence, a particular configuration may use any number of the following techniques to ensure that adequate position data is derived during a screening process.

Therefore, it is to be understood that one or more of the following arrangements may be used in the x-ray screening apparatus 2₀ of the present invention. Moreover, any of these arrangements may be installed in a modified prior art screening apparatus, to remove the need for a complex synchronised drive mechanism etc.

According to a preferred arrangement, the head and source assemblies 30, 2 are each respectively adapted to include at least one acoustic transmitter or at least one acoustic receiver. Either assembly may be selected to host the transmitter (or respectively, the receiver), but in practical applications it is expected that the transmitter will be associated with the x-ray source 2₀. Preferably, the transmitter/receiver operate in ultrasonic wavebands, to avoid unnecessary noise disturbance for the operator within the screening environment. However, it is to be appreciated that, any suitable sound wave may be used, provided a recognisable signal from the transmitter can be detected by the receiver.

The transmitter may form part of the source assembly 2 circuitry, or alternatively, may be a separate unit that can be attached directly to the assembly 2₀. In either case, the transmitter will preferably be controlled by the operator, and will usually be activated automatically when the apparatus is in use. The transmitter is arranged to transmit pulsed ultrasonic sound waves towards the detector, which are then received by the receiver attached to the detector assembly 30. Due to the separation of the source 2₀ and detector 1, an inherent delay in receiving the pulse will occur relative to the time of transmission. Therefore, this time-delay can be

determined to provide a measurement of the relative displacement between the source 2₀ and the detector 1, having knowledge of the speed of propagation of the ultrasonic wave pulse.

5 Preferably, the detector assembly 30 includes a controller, comprising a timing circuit, which is synchronised with the transmitter circuitry, so that the time-delays associated with each pulse can be calculated and used to determine the corresponding separations between the source 2₀ and detector 1. As the source 2₀ and detector 1 move relative to one another during screening, the separation
10 between them will change accordingly, and therefore the timing circuit can automatically calculate the relative displacement between the source 2₀ and detector 1, which can then be logged against a time stamp for use during image reconstruction.

15 To determine the relative orientation between the source 2₀ and the detector 1, at least three receivers are required at the location of the detector assembly 30. This is to enable the angular displacement of the detector 1 to be determined relative to the source 2₀, in any of the three coordinate axes. By using at least three receivers, the timing circuit can determine the time-delay for a pulse to be detected by each
20 of the three receivers, and therefore having knowledge of their spatial separation (i.e. inter-receiver separation) and speed of propagation of the pulse, can calculate the angle (and hence orientation) of the detector 1 relative to the source 2₀ based on each of the displacements of the receivers relative to the source 2₀.

25 It is to be appreciated that any number of transmitters and receivers may be used in the x-ray screening apparatus 20 according to the present invention, depending on the particular application. Moreover, the transmitters and receivers may be spatially arranged in any suitable array structure or configuration, to provide reliable and accurate position determination for the detector 1 relative to the
30 source 2₀, and vice versa.

Furthermore, it is to be understood that the above technique may also be implemented using light or radio based transmitters and receivers, and therefore is

not limited to acoustic implementations. For instance, the transmitter may be a light source, such as an optical or Infra-Red (IR) laser, and the receivers may be any suitable photodetector device. In such applications, the timing circuit would be a high speed timing device to take the significantly faster propagation speeds
5 into consideration. Radio based implementations would use radio-frequency (RF) pulsed waveforms and receivers would be conventional radio antennae and amplifier circuitry.

In an alternative arrangement, the displacement and/or orientation of the source 2_0
10 and detector 1 relative to each other may be determined by use of a mask device. The mask device is preferably in the form of a 'shadow mask', which is a physical device which can be attached or mounted to either the detector 1 or source 2_0 , or both. The purpose of the mask is to generate a recognisable shadow pattern in an x-ray image generated by the detector 1. Using suitable processing algorithms, the
15 relative displacement and/or orientation of the source 2_0 and the detector 1 can be calculated based on the shape, size and/or location of the shadow pattern in the captured image data.

The mask can be formed from any suitable x-ray opaque material or composite
20 material, and can have any geometric shape. Preferred mask shapes are non-symmetrical, having a unique shape defined by their outer perimeter. This allows the rotation of the detector 1 relative to the source 2_0 to be determined by analysis of the orientation of the shadow with respect to a part of the detector 1. The mask is preferably attached directly to the detector assembly 30, and may be positioned
25 close to the detector's surface. Alternatively, or additionally, the mask (or additional mask) can be attached to the source 2_0 , so that a shadow is formed within the emission cone of the source 2_0 .

In some arrangements, a mask may alternatively include one or more shaped
30 apertures across its surface, thereby being partially transparent to x-rays. Use of such apertures can allow unique mask shadows to be produced, which can aid identification and processing of a shadow within captured image data.

It is to be appreciated that any number of masks may be used according to the present invention, depending on the particular application. Moreover, in preferred arrangements, the mask or masks may be switchable, in that they can be selectively switched into or out of the image plane of the detector 1, prior to or
5 during image capture, after having served to determine the relative positions of the source 2_0 and detector 1 at that time.

The position of the shadow in the resulting captured image is dependent on the relative orientation of the source 2_0 and detector 1. Therefore, there is a functional
10 relationship between the shadow position and angular displacement of the detector 1 relative to the source 2_0 . Hence, this relationship can be pre-calibrated during fabrication of the apparatus 20 to permit the relative orientation of the source 2_0 and the detector 1 to be determined during screening.

15 The mask and detector can be arranged so that the shadow is always cast on a dedicated portion of the detector, e.g. a corner of the detector surface. Alternatively, the shadow can be made to fall onto a non-imaging part of the detector, e.g. a border of the detector. In this way, the image processing algorithms have *a priori* knowledge of where the shadow is expected to reside in any
20 particular image, and therefore processing of the shadow can begin quickly, permitting rapid determination of the relative orientation of the source 2_0 and detector 1.

A change in the position of the shadow in the image data may take the form of a
25 relative change in both horizontal and vertical axes of the shadow, and a change in size of the shadow would be indicative of a change in the relative displacement between the source 2_0 and detector 1.

The processing of the shadow information in the image data can be performed by
30 a dedicated processor, which preferably forms part of the control unit 40 (discussed earlier in relation to figure 9), or alternatively, the shadow processing can form part of the processing algorithms used for image reconstruction and can be executed on an image processor.

It is to be appreciated that other arrangements may alternatively, or additionally, be used in order to determine the relative displacement and/or orientation between the source and detector, all of which are consistent with the present invention. In particular, in the transmitter/receiver based applications, the transmitter need not
5 be mounted to the source assembly, and could instead form part of a transmitter array etc. including a plurality of transmitters disposed at specific locations within and/or around the screening environment. In this way, receivers mounted to both the source and detector assemblies 30, 2 would receive pulsed signals from the transmitter array and the corresponding time-delays could be calculated with
10 reference to the location of the transmitters. The relative displacement and/or orientation of the source and detector could then be calculated accordingly.

Hence, in a more general sense, the x-ray screening apparatus includes a remote sensing system for determining the relative position and orientation of the source
15 and detector relative to one another either directly or by reference to an independent reference frame (e.g. some remote positioning transmitters or beacons, or even the walls or structures surrounding the screening environment etc.).

20 Although the X-ray screening apparatus of the present invention is ideal for inspecting baggage and luggage in airport environments and security check-in points, it will be recognised that the apparatus can be extended to other applications, including inspecting freight, cargo and small to medium size vehicles at depots, ports and terminals.

25 Other embodiments are taken to be within the scope of the accompanying claims.

CLAIMS

1. An x-ray screening apparatus, comprising:
at least one x-ray source;
5 at least one x-ray detector; and
a sampling volume disposed between the source and the detector;
the apparatus being configured such that the at least one detector is able to
receive radiation from the at least one source which radiation has passed through
each spatially resolvable volume element within the sampling volume at at least
10 two different angles of incidence, and
in which at least two of the source, detector and sampling volume are
relatively displaceable so as to enable fully independent relative displacement of
each of the source, detector and sampling volume.
- 15 2. The apparatus of claim 1, wherein at least one of the source, detector and
sampling volume is adapted to move in a linear or arcuate motion.
3. The apparatus of claims 1 or 2, further comprising a drive mechanism
associated with each of at least two of the source, detector and sampling volume.
- 20 4. The apparatus of claim 3, wherein each drive mechanism is operable to
move one of the source, detector and sampling volume, independently of the
others.
- 25 5. The apparatus of any preceding claim, wherein the source is adapted to
produce a cone of x-rays having an angular extent sufficient to completely
irradiate the sampling volume.
6. The apparatus of any preceding claim, wherein the source is adapted to
30 operate over a variable range of x-ray energies.
7. The apparatus of any of claims 1 to 5, wherein the source is adapted to
operate at a plurality of different discrete x-ray energies.

8. The apparatus of claim 1, wherein the source comprises a plurality of spatially separated emission sites.
- 5 9. The apparatus of claim 8, wherein the emission sites are disposed along an axis substantially transverse to the axis of separation of the source and detector.
10. The apparatus of claims 8 or 9, wherein each emission site is configured to emit radiation independently of the other sites.
- 10 11. The apparatus of any of claims 8 to 10, wherein each emission site is configured to emit radiation at different x-ray energies.
12. The apparatus of any of claims 8 to 11, wherein the emission sites are
15 configured to emit radiation in an ordered sequence of emission.
13. The apparatus of claim 12, wherein the ordered sequence of emission is cyclic.
- 20 14. The apparatus of claims 12 or 13, wherein the ordered sequence of emission is linked to a plurality of detector sweeps, each detector sweep resulting in radiation being received at the at least one detector from one of the emission sites.
- 25 15. The apparatus of any of claims 12 to 14, wherein the ordered sequence of emission is dependent on the position of the detector relative to the source and sampling volume.
- 30 16. The apparatus of any of claims 1, 2 and 5 to 15, further comprising a control unit coupled to the detector to receive data corresponding to the detected radiation.

17. The apparatus of claim 16, wherein the control unit is further coupled to the source to control the emission of the radiation.
18. The apparatus of claims 16 or 17, wherein the control unit is coupled to a drive mechanism associated with at least one of the source, detector and sampling volume for controlling the relative displacement of the source, detector and sampling volume.
19. The apparatus of claim 18, wherein the control unit is coupled to at least one of the source, detector and drive mechanism by wireless communications.
20. An x-ray screening apparatus, comprising:
at least two spatially separated x-ray sources;
at least one x-ray detector;
a sampling volume disposed between the sources and the detector;
the apparatus being configured such that the at least one detector is able to receive radiation from the at least two sources which radiation has passed through each spatially resolvable volume element within the sampling volume at at least two different angles of incidence, and
in which the sources and detector are relatively displaceable along an axis that is transverse to the axis of separation of the sources and detector.
21. The apparatus of claim 20, wherein each source is adapted to produce a cone of x-rays having an angular extent sufficient to irradiate the sampling volume.
22. The apparatus of claims 20 or 21, wherein each source is adapted to operate over a variable range of x-ray energies.
23. The apparatus of claims 20 or 21, wherein each source is adapted to operate at a plurality of different discrete x-ray energies.

24. The apparatus of any of claims 20 to 23, wherein the sources are contained within a source assembly, each source corresponding to an emission site on an outwardly facing surface of the assembly.
- 5 25. The apparatus of claim 24, wherein each emission site is configured to emit radiation independently of the other site.
26. The apparatus of any of claims 1 to 25, wherein the detector includes at least one 1-dimensional array of x-ray sensitive elements.
- 10 27. The apparatus of claim 26, wherein the detector includes a plurality of 1-dimensional arrays of x-ray sensitive elements, arranged one-in-front-of-the-other along a line of sight between the source and detector.
- 15 28. The apparatus of claims 26 or 27, wherein the x-ray sensitive elements are arranged in an alternating pattern of varying thickness.
29. The apparatus of any of claims 26 to 28, wherein each array has an associated x-ray absorbent layer substantially co-located with alternating x-ray
20 sensitive elements.
30. The apparatus of any of claims 1 to 29, wherein the detector is a single x-ray sensitive element, and the apparatus further comprises a drive mechanism associated with the single element to position the element relative to the source
25 and sampling volume.
31. The apparatus of claim 30, wherein the drive mechanism has at least two degrees of freedom.
- 30 32. The apparatus of any of claims 1 to 31, wherein the detector is integral with, or contained within, a detection head assembly.

33. The apparatus of any of claims 1 to 32, wherein the source is mounted within a source assembly.
34. The apparatus of claim 20, further comprising a control unit coupled to the
5 detector to receive data corresponding to the detected radiation.
35. The apparatus of claim 33, wherein the control unit is further coupled to the sources to control the emission of the radiation.
- 10 36. The apparatus of claims 34 or 35, wherein the control unit is coupled to a drive mechanism associated with the detector for controlling the position of the detector relative to the sources.
37. The apparatus of claim 36, wherein the control unit is coupled to at least
15 one of the sources, detector and drive mechanism by wireless communications.
38. The apparatus of any of claims 16 to 19 and 34 to 37, wherein the control unit includes a processing means adapted to interpret the received data so as to produce an image of the sampling volume.
- 20 39. The apparatus of claim 38, wherein the processing means interprets the received data via an image processing algorithm.
40. The apparatus of claims 38 or 39, wherein the image is a stereoscopic
25 representation of the sampling volume.
41. The apparatus of claim 40, wherein the image is adapted for viewing by a display monitor or virtual reality headset.
- 30 42. The apparatus of claim 1 or claim 20, further comprising means associated with at least one of the source and the detector adapted to automatically determine the relative displacement and/or orientation of the source and detector with respect to each other.

43. An x-ray screening apparatus, comprising:
at least one x-ray source;
5 at least one x-ray detector; and
a sampling volume disposed between the source and the detector;
the apparatus being configured such that the source and detector are able to
move independently of each other, and
further comprising means associated with at least one of the source and the
10 detector adapted to automatically determine the relative displacement and/or
orientation of the source and detector with respect to each other.
44. The apparatus of claim 43, wherein the determining means comprise at
least one transmitter and at least one receiver for communication therebetween,
15 each associated with a respective one of the source and the detector.
45. The apparatus of claim 44, wherein the determining means further
comprises a controller operable to calculate the relative displacement between the
source and the detector based on the time taken for transmissions to be received at
20 the at least one receiver.
46. The apparatus of claim 44 or claim 45, wherein the at least one receiver
includes an array of spatially displaced receivers for determining the relative
orientation of the source and detector with respect to each other.
25
47. The apparatus of any of claims 44 to 46, wherein the at least one x-ray
source and the at least one x-ray detector are each contained within a separate
head assembly, and the at least one transmitter and the at least one receiver are
each associated with a respective one of the assemblies.
30
48. The apparatus of any of claims 44 to 47, wherein the at least one
transmitter and the at least one receiver are arranged to communicate by one or
more of the following wave types: acoustic, light and radio.

49. The apparatus of claim 48, wherein the transmissions comprise pulsed waveforms.

5 50. The apparatus of claim 43, wherein the determining means comprise a mask for generating a recognisable shadow pattern in an x-ray image generated by the at least one x-ray detector.

51. The apparatus of claim 40, further comprising a processor arranged to
10 calculate the relative displacement and/or orientation of the source and the detector, based on the shape, size and/or location of the shadow pattern of the mask in an x-ray image generated by the at least one x-ray detector.

52. The apparatus of claim 50 or claim 51, wherein the mask may comprise
15 one or more masks, each mountable to the at least one detector and/or the at least one source.

53. The apparatus of any of claims 50 to 52, wherein the mask is configured to be selectively switched into or out of the image plane of the at least one x-ray
20 detector.

54. The apparatus of claim 50, wherein the apparatus is configured to enable the shadow pattern of the mask to be cast onto a dedicated portion of the detector.

25 55. The apparatus of claim 50, wherein the mask is x-ray opaque across its surface and has a unique shape defined by its outer perimeter.

56. The apparatus of claim 50, wherein the mask is partially transparent to x-rays across some of its surface.

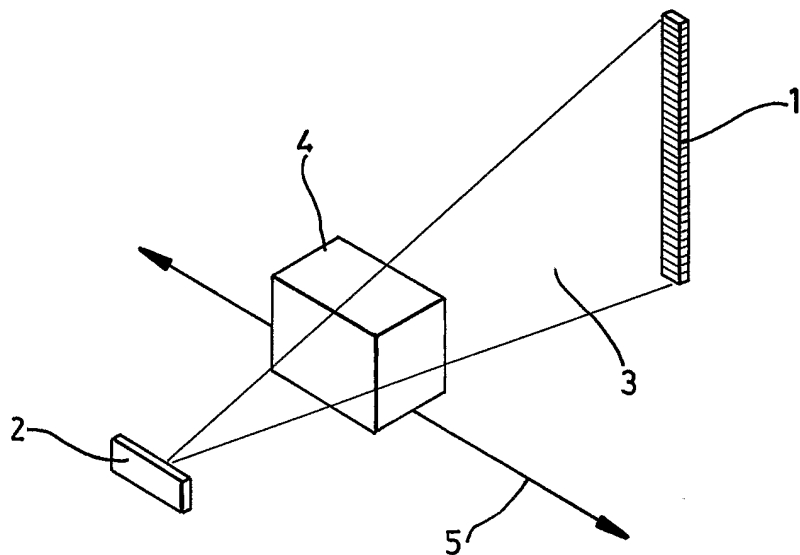
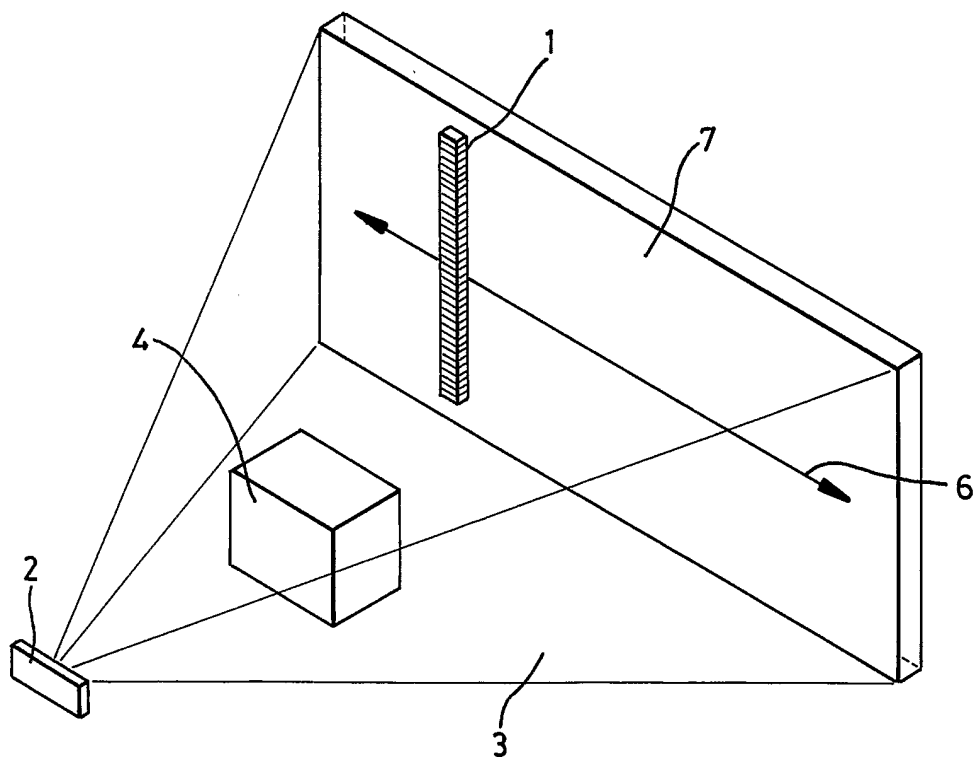
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57. The apparatus of any of claims 43 to 56, wherein the apparatus is further configured such that the at least one detector is able to receive radiation from the at least one source which radiation has passed through each spatially resolvable

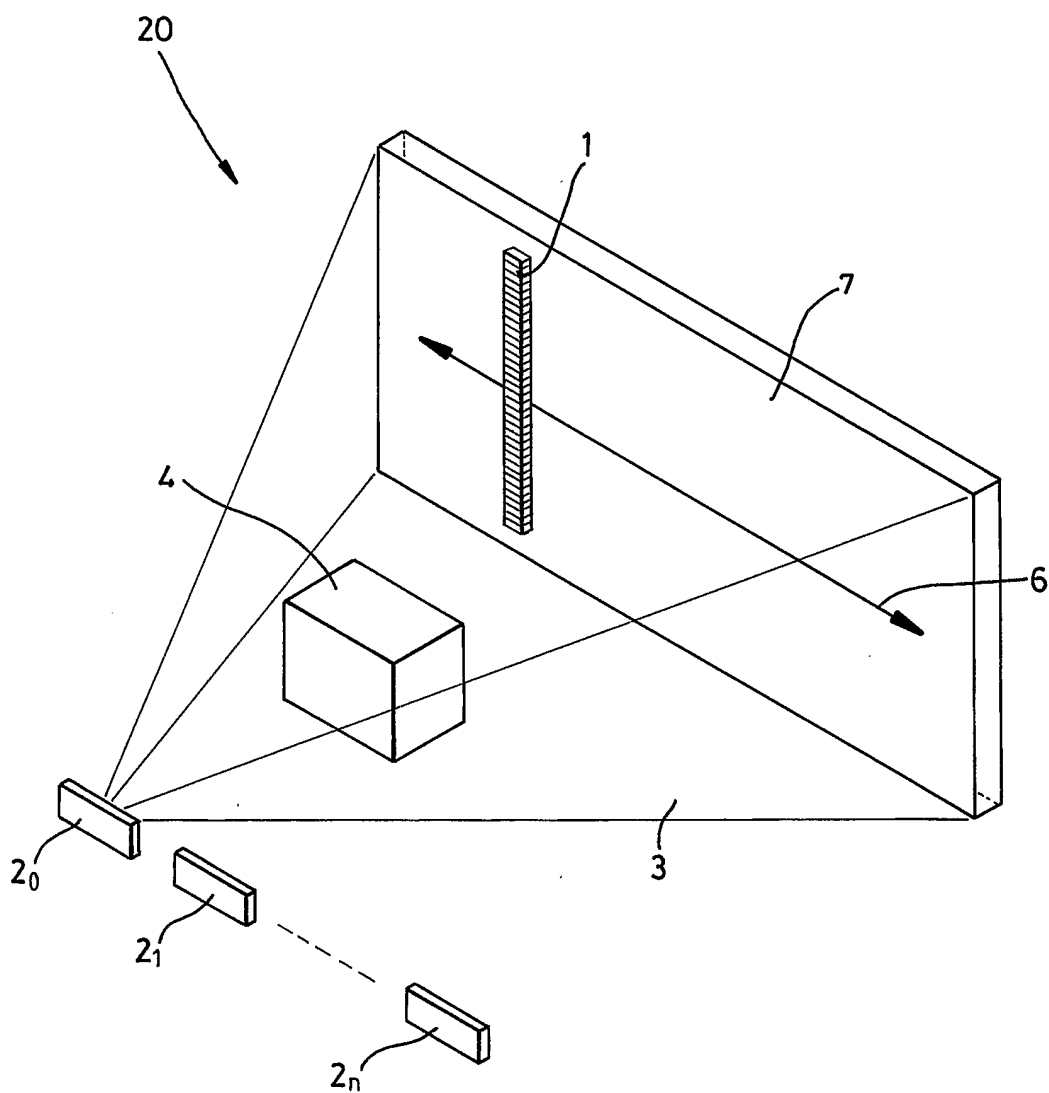
volume element within the sampling volume at at least two different angles of incidence.

58. Apparatus substantially as described herein with reference to the
5 accompanying drawings

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*Fig. 1**Fig. 2*

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*Fig. 3*

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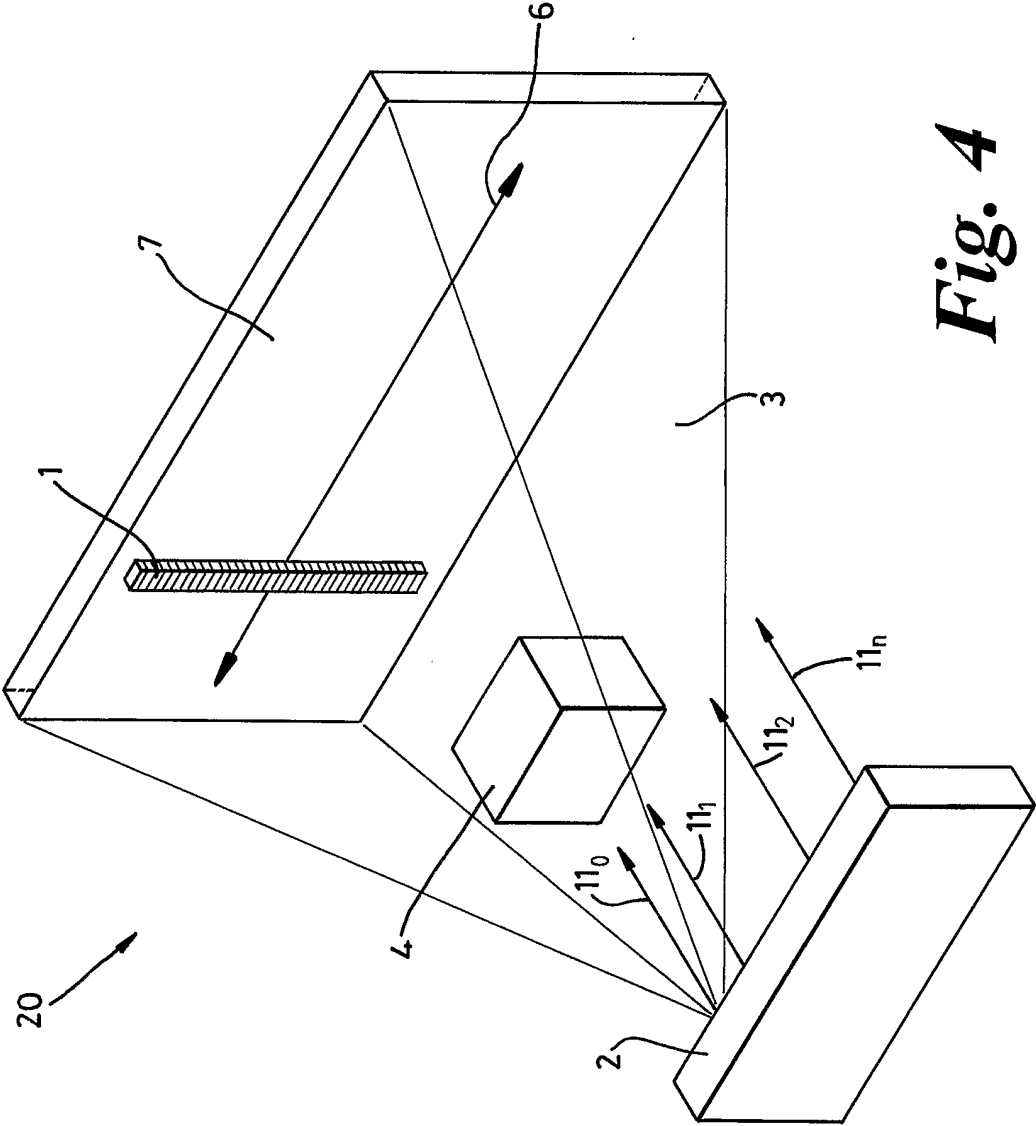
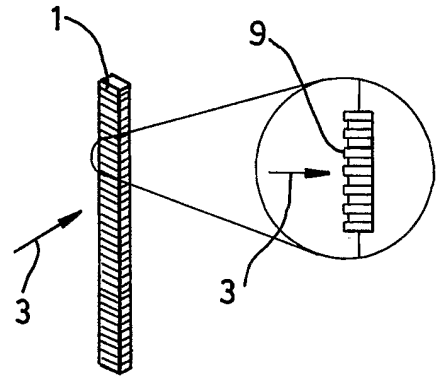
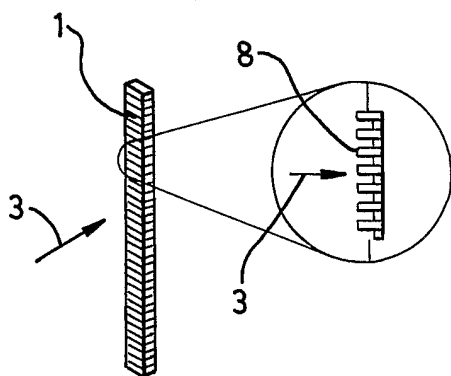
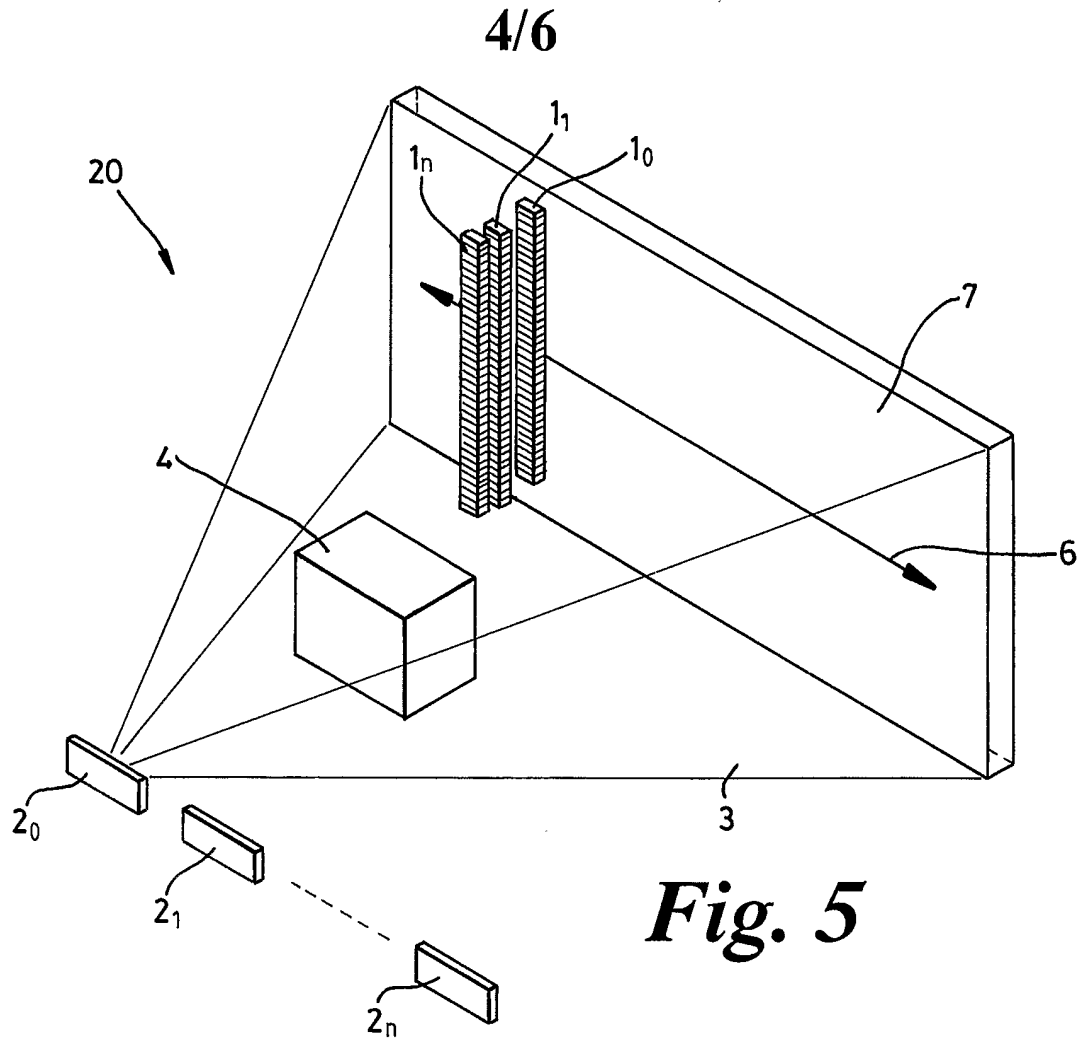
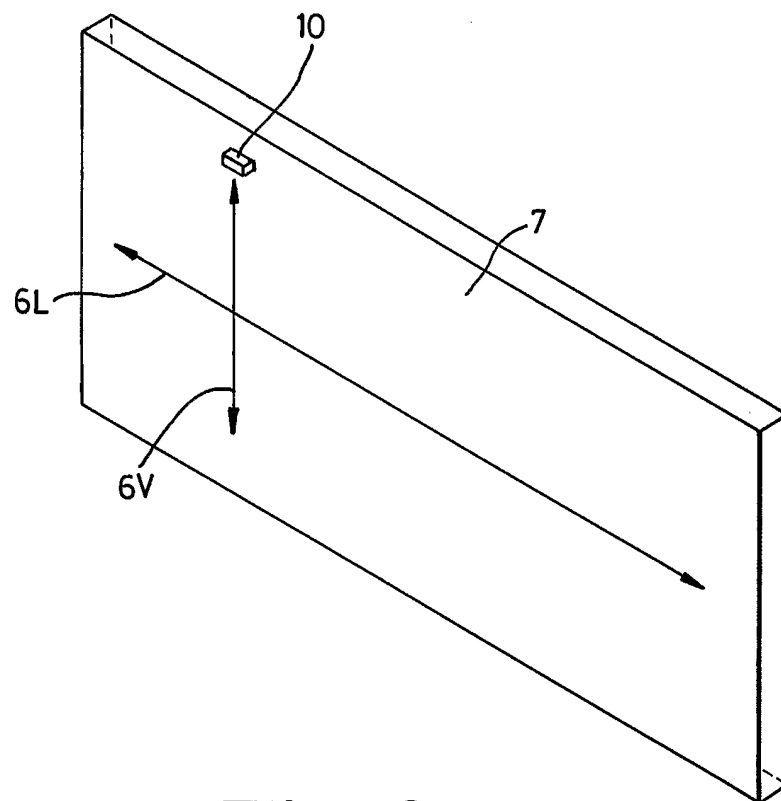


Fig. 4



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*Fig. 8*

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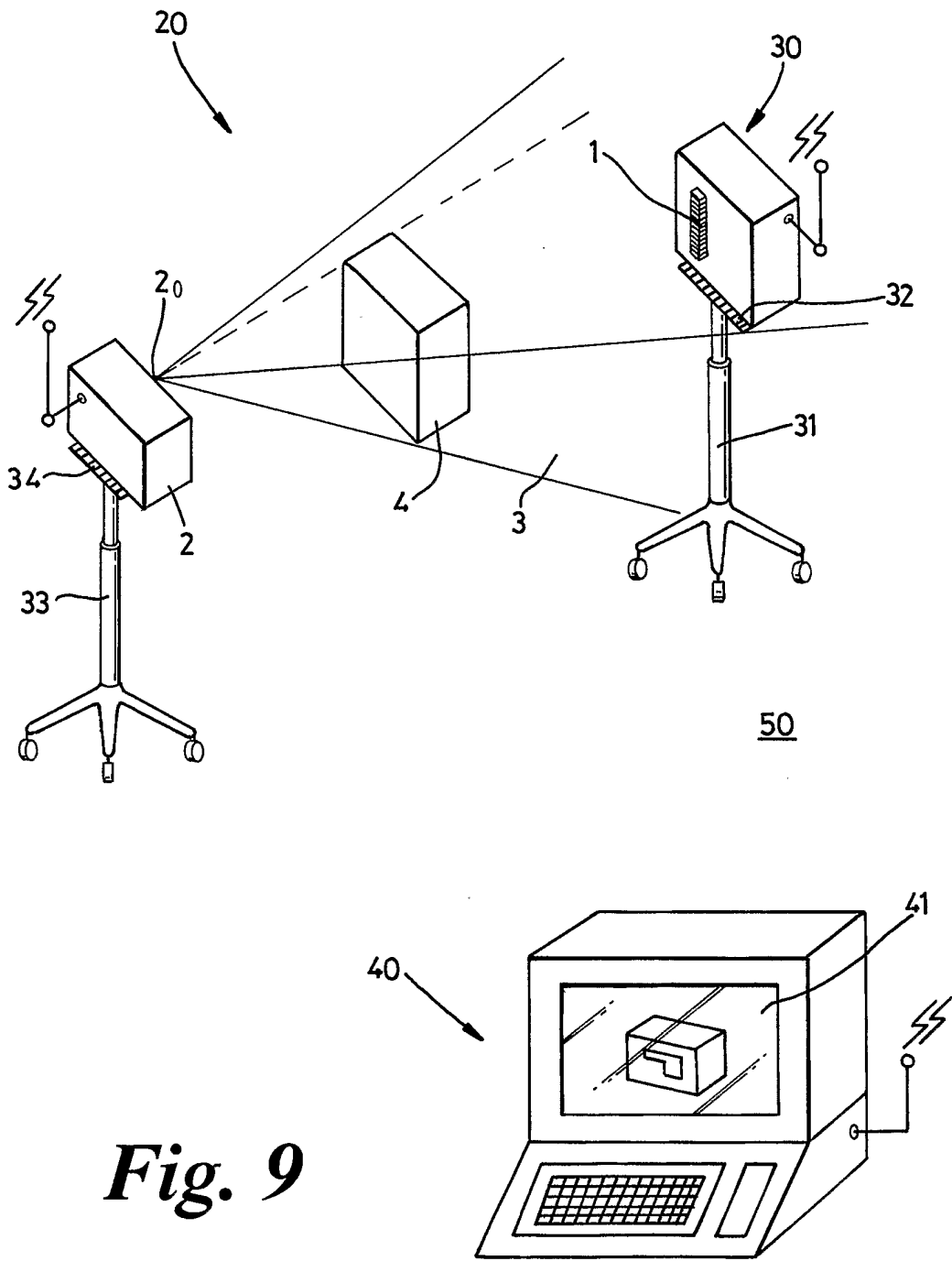


Fig. 9