

Backscatter Inspection Portal

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Field of the Invention

The present invention relates to systems and methods for inspecting objects with penetrating radiation, and, more particularly, the invention relates to inspection systems employing multiple sources of radiation.

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Background of the Invention

It is desirable to determine the presence of objects, such as contraband, weapons, or explosives, that have been concealed, for example, in a moving vehicle, or on a person, or in any inspected object, while the inspected object is moved past one or more systems that image the contents of the object using penetrating radiation. The determination
15 should be capable of being made while the inspected object is in motion, or, alternatively, while the inspection system is in motion with respect to the inspected person or object. Indeed, since inspection rate, and thus hourly throughput, is at a premium, it is desirable that the vehicle, for example, be driven without requiring the driver or passengers to alight. In case a detection is made, a visual image should be available for verification.

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The use of images produced by detection and analysis of penetrating radiation scattered from an irradiated object, container, or vehicle is the subject, for example, of US Patent No. 6,459,764, to Chalmers et al. (the "Chalmers Patent"), issued October 1, 2002. The Chalmers Patent teaches backscatter inspection of a moving vehicle by illuminating the vehicle with x-rays from above or beneath the moving vehicle, as well as from the
25 side.

The use of an x-ray source and an x-ray detector, both located in a portal, for purposes of screening personnel, is the subject, for example, of US Patent No. 6,094,072, to Smith, issued July 25, 2000.

X-rays are scattered from matter in all directions, therefore, scatter may be
30 detected by an x-ray detector disposed at any angle to the scattering material with respect to the direction of incidence of the illuminating radiation. Therefore, a "flying spot"

irradiation system is typically used, whereby a single point on the inspected object is illuminated with penetrating radiation at any given moment, so that the locus of scatter can be determined unambiguously, at least with respect to the plane transverse to the direction of the beam of penetrating radiation.

5 In order to obtain multiple views of an inspected object, multiple backscatter imaging systems may be employed in a single inspection tunnel. This may result in interference, or cross-talk, between respective imaging systems, resulting in image degradation. This is due to the lack of each flying-spot imager's ability to distinguish the origin of the scattered radiation from each imager's source. To date, this problem has
10 been addressed by placing the imagers some distance apart to minimize cross talk. This approach causes the size of the overall system to increase. In space-limited applications, this is often undesirable.

Summary of the Invention

 In one embodiment of the present invention, there is provided an inspection
15 system for inspecting an object that is characterized by motion in a particular direction with respect to the inspection system, by virtue of motion with respect to the local frame of reference of either the object, the inspection system, or both. The inspection system has a first source for providing a first beam of penetrating radiation of specified cross-section directed in a first beam direction substantially transverse to the direction of
20 motion of the object. It also has a second source for providing a second beam of penetrating radiation in a second beam direction, and may have additional sources of additional beams. The beams of penetrating radiation are temporally interspersed. Additionally, the system has a plurality of scatter detectors for detecting radiation scattered from at least one of the first beam and the other beams by any scattering
25 material within the inspected object and for generating a scattered radiation signal. The system may also have one or more transmission detectors for detecting penetrating radiation transmitted through the object. Finally, the system has a controller for creating an image of the scattering material based at least on the scattered radiation signal or for otherwise characterizing the scattering material.

30 In accordance with alternate embodiments of the invention, the first source of penetrating radiation may be an x-ray source, as may the other sources of penetrating radiation. The first beam direction and the direction of any other beam may be

substantially coplanar. The various sources may include a beam scanning mechanism, such as a rotating chopper wheel or an electromagnetic scanner, and one or more of the beams may be pencil beams.

In accordance with yet further embodiments of the invention, emission of
5 penetrating radiation in the first beam may be characterized by a first temporal period and emission of penetrating radiation in the second beam may be characterized by a second temporal period, the first and the second temporal periods offset by fixed phase relationship. The temporal period of each source may be characterized by a duty cycle, and the emission of adjacent sources may be characterized by a phase relationship with
10 respect to an adjacent source, where the phase relationship may equal to 2π times the duty cycle.

In accordance with yet further embodiments of the invention, the inspection system may further including a display for displaying a scatter image of material disposed within the inspected object.

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Brief Description of the Drawings

The foregoing features of the invention will be more readily understood by reference to the following detailed description, taken with reference to the accompanying drawings, in which:

20 Fig. 1 shows a schematic cross sectional view of an x-ray inspection system that uses multiple backscatter imaging systems in accordance with embodiments of the present invention; and

Fig. 2 shows a side view of the x-ray inspection system embodiments of Fig. 1.

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Detailed Description of Specific Embodiments

In accordance with embodiments of the present invention, beam cross talk is minimized between or among multiple flying-spot backscatter imaging systems configured as a multi-view backscatter inspection system, with no restriction on the distance between the individual imaging systems. In other
30 words, in a multi-view system comprised of individual backscatter imaging systems for each view, the individual imaging systems can be placed as close

together as is physically possible, while cross talk is advantageously reduced or eliminated.

Methods and advantages of backscatter inspection of a moving vehicle by illuminating the vehicles with x-rays from either above or beneath the moving vehicle are described in US Patent No. 6,249,567, issued June 19, 2001, which is incorporated herein
5 by reference. In accordance with preferred embodiments of the present invention, regions of enhanced backscatter that arise due to materials concealed close to the side walls of a vehicle are revealed without requiring that penetrating radiation traverse the vehicle during the course of inspection.

10 Fig. 1 shows a schematic cross-sectional view of the elements of an inspection system, designated generally by numeral 10. An object of inspection 18, which may be animate or inanimate, moves, or is moved, in a direction into, or out of, the page and thus traverses a portal 12. Portal 12 supports a plurality of sources 13, 15, and 17 of penetrating radiation. Sources 13, 15, and 17 are typically x-ray tubes having beam
15 forming and steering mechanisms known in the art. For example, source 13 emits penetrating radiation in a beam 23 having a cross-section of a specified shape. For scatter imaging applications, a narrow pencil beam is typically employed. Beam 23 of penetrating radiation, may be, for example, a beam of x-rays such as a polychromatic x-ray beam. While source 13 of penetrating radiation is preferably an x-ray tube, for
20 example, however other sources of penetrating radiation, such as a linac (linear accelerator), are within the scope of the present invention, and, indeed, the penetrating radiation is not limited to x-ray radiation and may include gamma ray radiation.

A scanning mechanism is provided for scanning beam 23 along a substantially vertical axis, such that, during a portion of a duty cycle, beam 23 is directed in a series of
25 directions such as 24. Object 18 that is to be inspected moves past beam 23 in a substantially horizontal direction, into the page, in the depiction of Fig. 1. In alternate embodiments of the invention, the source and/or other portions of the inspection system may be moved in relation to object 18, which may be moving itself, or stationary.

Source 13 may include a scanning mechanism such as a flying spot rotating
30 chopper wheel as known to persons skilled in the art. Alternatively, electromagnetic scanners may be employed, such as those described in U.S. Patent No. 6,421,420, issued July 23, 2002 and entitled "Method and Apparatus for Generating Sequential Beams of Penetrating Radiation," which is incorporated herein by reference.

Beams of sources **15** and **17** are shown in typical extremal positions of their respective scans, and are labeled **25**, **26**, **27**, and **28**. Inspected object **18**, which, as discussed, may refer to a vehicle, a container, or a person, for example, may be self-propelled through beams **23-28** or may be conveyed by a mechanized conveyor or pulled
5 by a tractor, etc. In alternate embodiments of the invention, the inspection system, configured, for example, as a portal, may move, or be moved, over an object such as a vehicle that may, itself, be moving or stationary.

Beams **23-28** will be referred to in the present description, without limitation, as x-ray beams. In accordance with preferred embodiments of the invention, a rotating
10 chopper wheel is used to develop a pencil beam **23-28** which may be swept in a plane substantially parallel to that of the page. The cross section of pencil beam **23** is of comparable extent in each dimension and is typically substantially circular, although it may be many shapes. The dimensions of pencil beam **23-28** typically define the scatter image resolution which may be obtained with the system. Other shapes of beam cross
15 section may be advantageously employed in particular applications.

A detector arrangement, typified by scatter detector **31**, is disposed in a plane parallel to the direction of motion of object **18** during the course of the scan. X-rays
30 scattered by Compton scattering out of beam **24** in an essentially backward direction are detected by one or more backscatter detectors **31** disposed between source **13** and
20 object **18**. Additional detector arrangements **32**, **33**, **34**, **35**, and **36** may be used supplementarily for detecting x-rays Compton-scattered from beam **24** and similarly, as will presently be described, for each of the other beams incident, in turn, on inspected object **18**.

Additionally, transmission detectors disposed distally to the inspected object **18**
25 with respect to the emitting source may be used to augment the scatter image or images with an image of the object as obtained in transmitted x-rays, for example, the detector elements designated **35** and **36** detect the emission of source **13** as transmitted through the inspected object. In another embodiment of the invention, a single separate detector is disposed between the pair of scatter detectors **35** and the pair of scatter detectors **36** and is
30 employed for detection of penetrating radiation transmitted through object **18**.

Within the scope of the invention, any x-ray detection technology known in the art may be employed for the detector arrangements **31-36**. The detectors may be scintillation materials, either solid or liquid or gaseous, viewed by photo-sensitive detectors such as

photomultipliers or solid state detectors. Liquid scintillators may be doped with tin or other element or elements of high atomic number. Respective output signals from the scatter detectors **31-36** are transmitted to a processor **40**, and processed to obtain images of feature **42** inside the inspected object **18**. Since incident x-ray photons are scattered by scattering sources within object **18** into all directions, detectors with large areas are used to maximize the collection of the scattered photons. In accordance with certain embodiments of the invention, processor **40** (otherwise referred to herein as a 'controller') may also be employed to derive other characteristics of the scattering object, such as its mass, mass density, effective atomic number, etc., all as known in the art.

10 In order to allow views of the inspected object from multiple directions, multiple sources **13-17** are used to irradiate the inspected object. However, since the photons emitted by each source are scattered in all directions, care must be exercised in order to eliminate cross-talk, i.e., the misidentification of the source of irradiation. In accordance with embodiments of the present invention, cross talk is advantageously reduced or eliminated by ensuring that only one imager is emitting radiation at a time. First, the duty-cycle of the beams emitted from the imaging systems is set less-than or equal-to the inverse of the number of imaging systems, or views, in the multi-view system. For example, if the number of views desired is six, each imaging system is set for a duty cycle of $1/6$, or less.

20 Next, the phase relationship between each pair of adjacent sources is set to 2π times the duty cycle. This results in sequenced radiation emission from the imagers, eliminating the possibility of concurrent emission from more than one imager. For example, a multi-view inspection system with 6 sources would require that they run at the same frequency, that their duty-cycles be $1/6$, and that their phase relationship be $2\pi/6$, or 60 degrees.

25 In cases where flying-spot systems are realized by mechanical means such as rotating hoops and chopper wheels, these aforesaid criteria may be met by synchronization of the motion of the mechanical chopper elements, biased by phase offsets. Thus, for example, where collimators are rotated to define the path of emergent x-ray beam **23**, close-loop motion controller systems known in the art may be employed to drive the rotation of the collimators. The duty cycle is controlled by setting the fan aperture (the total sweep angle of a beam, i.e., the angle between extremal beams **23** and **24** of a single source), equal to 2π times the duty cycle. In systems where the emitted

radiation can be controlled electronically, any desired sequence of irradiation or range of sweep may be set, without limitation, entirely by electronic or software control.

By virtue of temporal sequencing which reduces or eliminates cross-talk, sources may be placed in greater proximity than otherwise possible. In particular, sources **13-17** may be disposed in a single plane, which advantageously permits virtually simultaneous on/off control of the x-rays regardless of the speed with which the object is passing by the imagers.

The system described may advantageously provide for an image to be derived from the perspective of each successive source **13-17**. Fig. **1** shows an exemplary three-view system, with beams **23, 25**, etc. each sweeping trajectories that are coplanar.

The beams from each imager sweep in sequence, such that no more than one imager is emitting radiation at a time. Thus, source (or 'imager') **13** sweeps its beam first. Radiation scattered from the object, as represented by rays **44**, is received by all of the detectors. The signals from each of the detectors are acquired as separate channels by an acquisition system. This process is repeated for each of the three imagers, creating "slices" of the object as it moves by.

Referring now to Fig. **2**, a side view is shown of the arrangement of Fig. **1**, with elements designated by corresponding numbers. A slot **50** is shown through which the beam of source **13** passes through segments **52** and **54** of detector **31** as object **18** is scanned while moving in a lateral direction **16**.

The signals from the detectors can be selectively used to reconstruct an image of the object. Since scattered photons **44** detected by detectors **33** and **34** from source **13** are as useful as scattered photons from source **17**, these same detectors can be shared among all sources, and result in improved scatter collection with efficient use of the detector hardware.

Embodiments of this invention, furthermore, may advantageously allow multi-view Flying-Spot X-ray Scatter imaging to be practiced in a smaller operational footprint by eliminating cross talk, and by allowing closer positioning of the individual imagers for each view. The close positioning of these imagers (where an "imager" refers to a source, at least one detector, and associated electronics and signal processing) may also allow sharing of scatter detectors between, or among, imagers, allowing more scatter collection for improved image quality, with efficient use of detector hardware.

In applications where scanning of selective regions of the object is desired, co-planar positioning of the imagers allows simultaneous on/off control of the x-rays regardless of the speed with which the object is passing by the imagers. This greatly simplifies the design of the control of x-ray emissions from each imager in the multi-view inspection system, thus individual sequencing of x-ray emissions need not be performed as is typically practiced in systems in which emission is not co-planar.

Besides imaging contents of concealing enclosures, in terms of which embodiments of the present invention have been described, other characteristics of inspected objects may be obtained within the scope of the present invention. For example, backscatter techniques may be applied, as known in the art, for deriving mass, mass density, mass distribution, mean atomic number, or likelihood of containing targeted threat material.

In accordance with certain embodiments of the invention, x-rays having maximal energies in the range between 160 keV and 300 keV are employed. At this energy, x-rays penetrate into a vehicle, and organic objects inside the vehicle can be detected. Since lower doses of x-ray irradiation are thus possible, automobiles may be scanned using the present invention. For applications where the scanned vehicle may contain personnel, end point energies below 300 keV are preferred. The scope of the present invention, however, is not limited by the range of penetrating photons employed.

The described embodiments of the invention are intended to be merely exemplary and numerous variations and modifications will be apparent to those skilled in the art. All such variations and modifications are intended to be within the scope of the present invention as defined in the appended claims.

WE CLAIM:

1. An inspection system for inspecting an object characterized by motion in a direction with respect to the inspection system, the system comprising:
 - a. a first source for providing a first beam of penetrating radiation of specified cross-section directed in a first beam direction substantially transverse to the direction of motion of the object;
 - b. a second source for providing a second beam of penetrating radiation of specified cross-section directed in a second beam direction and temporally interspersed with the first beam of penetrating radiation;
 - c. a plurality of scatter detectors for detecting radiation scattered from at least one of the first beam and the second beam by any scattering material within the inspected object and for generating a scattered radiation signal; and
 - d. a controller for creating an image of the scattering material based at least on the scattered radiation signal.
2. The inspection system as set forth in claim 1, wherein the inspection system is fixed with respect to a local frame of reference.
3. The inspection system as set forth in claim 1, wherein the inspection system is in motion, during the course of inspection, with respect to a local frame of reference.
4. The inspection system as set forth in claim 1, wherein the first source of penetrating radiation is an x-ray source.
5. The inspection system as set forth in claim 1, wherein the first beam direction and the second beam direction are substantially coplanar.
6. The inspection system as set forth in claim 1, wherein the first source of penetrating radiation includes a beam scanning mechanism.
7. The inspection system as set forth in claim 6, wherein the beam scanning mechanism is a rotating chopper wheel.
8. The inspection system as set forth in claim 6, wherein the beam scanning mechanism includes an electromagnetic scanner.
9. The inspection system as set forth in claim 1, wherein the first beam of penetrating radiation is a pencil beam.

10. The inspection system as set forth in claim 1, wherein emission of penetrating radiation in the first beam is characterized by a first temporal period and emission of penetrating radiation in the second beam is characterized by a second temporal period, the first and the second temporal periods offset by fixed phase
5 relationship.

11. The inspection system as set forth in claim 10, wherein the temporal period of each source is characterized by a duty cycle.

12. The inspection system as set forth in claim 11, wherein the temporal period of each source is characterized by phase relationship with respect to an adjacent
10 source equal to 2π times the duty cycle.

13. The inspection system as set forth in claim 1, further comprising a display for displaying a scatter image of material disposed within the object.

14. The inspection system as set forth in claim 1, further comprising at least one transmission detector for detecting at least one of the first beam and the second beam
15 as transmitted through the inspected object and for generating a transmitted radiation signal.

15. A method for inspecting an object, the method comprising:
a. illuminating the object with penetrating radiation formed into a first beam;
20 b. illuminating the vehicle with penetrating radiation formed into a second beam, the second beam temporally interspersed with respect to the first beam;
c. detecting radiation from the first beam and the second beam scattered by the object to generate a scattered radiation signal; and
25 d. characterizing the object on the basis of the scattered radiation signal.

16. A method according to claim 15, further including:
e. varying the orientation of the first beam with respect to the
vehicle.

30 17. A method according to claim 15, further including:
e. displaying a scatter image of the scattered radiation signal.

18. A method according to claim 15, wherein the step of characterizing the material disposed within the vehicle includes combining the scatter radiation signal

obtained during illumination with the first spectral composition with the scatter radiation signal obtained during illumination with the second spectral composition.

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