# MUON DETECTOR ARRAY STATIONS

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This patent document claims benefit of priority of U.S. Provisional Patent Application No. 61/817,264, entitled "MUON DETECTOR ARRAY STATIONS" and filed on April 29, 2013. The entire content of the aforementioned patent application is incorporated by reference as part of the disclosure of this patent document.

## TECHNICAL FIELD

**[0002]** This patent document relates to systems, devices, and processes that use imaging and sensing based on muon tomography.

## BACKGROUND

**[0003]** A muon is a charged particle with a unitary negative charge and a spin similar to an electron, but with a mass more than two hundred times greater than an electron. Muons can be generated by cosmic rays hitting the atmosphere and such cosmic-ray generated muons penetrate to the Earth's surface.

## SUMMARY

**[0004]** Muon tomography detection techniques, systems, and devices are described for implementing materials inspection stations based on naturally occurring and existing cosmic-ray generated muons on the Earth surface to inspect and identify target materials at various locations, e.g., such as roadway checkpoints, warehouses, airport hangers, seaports, and other inspection points.

**[0005]** In one aspect, a system for muon tomography detection includes a first housing structure including a first array of muon detection sensors, the first housing structure positioned along a first side adjacent to a detection region having a volume to contain a target object or vehicle, in which the muon detection sensors of the first array measure positions and directions of muons passing through to the detection region; a second housing structure including a second array of muon detection sensors, the second housing structure positioned along a second side opposite the first side and adjacent to the detection region and at a fixed height from the first housing structure, in which the muon detection sensors of the second array measure positions

and directions of the muons passing from the detection region through the second array; support structures to position the first housing structure at the fixed height; and a processing unit to receive data of the measured positions and directions from the first and second arrays of muon detection sensors and analyze scattering behaviors of the muons caused by scattering of the muons in materials of the target object within the detection region to obtain a tomographic profile or spatial distribution of scattering centers within the detection region. In some implementations, other exemplary detector configurations may be used, including, but not limited to, having a pair of detector arrays on either side of the target object, e.g., such as above and below the object and/or multiple opposing sides of the target object, e.g., such as having a side pair in addition to a pair above and below the object.

In another aspect, a vehicle inspection station having a built-in muon tomography inspection capability, comprising: a housing structure structured to at least partially enclose a vehicle and allow the vehicle to move in and out of the housing structure, the housing structure including a detection region to contain the vehicle; a first detection unit including a first array of one or more muon detection sensors, the first detection unit positioned along a first side of the housing structure adjacent to the detection region, wherein the one or more muon detection sensors of the first array measure positions and directions of muons passing through the first array to the detection region; a second detection unit including a second array of one or more muon detection sensors, the second detection unit positioned along a second side of the housing structure opposite the first side and adjacent to the detection region and at a fixed distance from the first detection unit, wherein the one or more muon detection sensors of the second array measure positions and directions of the muons passing from the detection region through the second array; a platform located in the detection region between the first and second detection units and configured to include a surface to receive and support a vehicle to be inspected, the platform including tracks or alignment marks for guiding the vehicle to a desired position on the platform to be inspected; and a processing unit to receive data of the measured positions and directions from the first and second arrays of one or more muon detection sensors, the processing unit configured to analyze scattering behaviors of the muons caused by scattering of the muons in materials of the vehicle within the detection region to obtain a tomographic profile or spatial distribution of scattering centers within the detection region.

In another aspect, a warehouse having a built-in muon tomography container inspection capability, comprising: a warehouse housing structure structured to include a roof over a storage area for placing storage containers, the warehouse housing structure including a detection region encompassing at least some of the storage containers; a first detection unit including a first array of one or more muon detection sensors, the first detection unit positioned along a first side of the housing structure adjacent to the detection region, wherein the one or more muon detection sensors of the first array measure positions and directions of muons passing through the first array to the detection region; a second detection unit including a second array of one or more muon detection sensors, the second detection unit positioned along a second side of the housing structure opposite the first side and adjacent to the detection region and at a fixed distance from the first detection unit, wherein the one or more muon detection sensors of the second array measure positions and directions of the muons passing from the detection region through the second array; and a processing unit to receive data of the measured positions and directions from the first and second arrays of one or more muon detection sensors, the processing unit configured to analyze scattering behaviors of the muons caused by scattering of the muons in materials of the storage containers within the detection region to obtain a tomographic profile or spatial distribution of scattering centers within the detection region.

In another aspect, a method of materials inspection in a storage facility using muon tomography, comprising: scanning a storage container stored in a storage facility using muon sensors to obtain muon tomography imaging data, the storage facility including housing structure having a first detection unit and a second detection unit positioned in a fixed alignment with respect to each other; moving the first detection unit and the second detection unit from a first position to a second position in the housing structure while maintain the fixed alignment between the first detection unit and the second detection unit; scanning a calibration marker of a known material located in the storage facility using muon sensors to obtain muon tomography imaging data; and determining, using a processing unit, the presence or lack of presence of a target material in the storage container based on the obtained muon tomography imaging data of the scanned storage container and the scanned calibration marker, wherein the first detection unit includes a first array of the muon sensors configured in a first plane and the second detection unit includes a second array of the muon sensors configured in a second plane parallel to the first plane, such that the muon sensors of the first array measure positions and directions of muons

passing through the first array and the muon sensors of the second array measure positions and directions of the muons passing from the detection region through the second array, and wherein the processing unit receives data of the measured positions and directions from the muon sensors and analyzes muon scattering behaviors caused by scattering of the muons in materials of the storage container.

**[0006]** These and other features are described in greater detail in the drawings, the description and the claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0007]** FIG. 1A shows an illustrative diagram of an exemplary muon tomography materials inspection station for automotive vehicles.

**[0008]** FIG. 1B shows an illustrative diagram of a lower detection unit of the exemplary muon tomography materials inspection station.

**[0009]** FIG. 2 shows an illustrative diagram of an exemplary muon tomography materials inspection station for aircraft.

**[0010]** FIG. 3A shows an illustrative diagram of an exemplary muon tomography materials inspection station for a warehouse or storage facility.

**[0011]** FIG. 3B shows an illustrative diagram of another exemplary muon tomography materials inspection station for a warehouse or storage facility.

**[0012]** FIG. 3C shows an illustrative diagram of another exemplary muon tomography materials inspection station for a warehouse or storage facility.

**[0013]** Like reference symbols and designations in the various drawings indicate like elements.

## DETAILED DESCRIPTION

**[0014]** Cosmic ray tomography is a technique which exploits the multiple Coulomb

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## SUMMARY

**[0004]** Muon tomography detection techniques, systems, and devices are described for implementing materials inspection stations based on naturally occurring and existing cosmic-ray generated muons on the Earth surface to inspect and identify target materials at various locations, e.g., such as roadway checkpoints, warehouses, airport hangers, seaports, and other inspection points.

**[0005]** In one aspect, a system for muon tomography detection having movable muon detection sensors, comprising: a first housing structure including a first array of one or more muon detection sensors, the first housing structure positioned along a first side adjacent to a detection region having a volume to contain a target object, wherein the one or more muon detection sensors of the first array measure positions and directions of muons passing through the first array to the detection region; a second housing structure including a second array of one or more muon detection sensors, the second housing structure positioned along a second side opposite the first side and adjacent to the detection region and at a fixed height from the first

platform to be inspected; a processing unit to receive data of the measured positions and directions from the first and second arrays of one or more muon detection sensors, the processing unit configured to analyze scattering behaviors of the muons caused by scattering of the muons in materials of the vehicle within the detection region to obtain a tomographic profile or spatial distribution of scattering centers within the detection region; and one or more fiducial markers formed of a known material and placed at known positions along a travel path of a positionally-aligned pair of detection sensors of the first and the second arrays, wherein the processing unit receives calibration data of the measured positions and directions of the muons passing through the known material of the fiducial marker to enable identification of a false positive or a false negative in the analyzed scattering behaviors of the muons.

In another aspect, a warehouse having a built-in muon tomography container inspection capability, comprising: a warehouse housing structure structured to include a roof over a storage area for placing storage containers, the warehouse housing structure including a detection region encompassing at least some of the storage containers; a first detection unit including a first array of one or more muon detection sensors, the first detection unit positioned along a first side of the housing structure adjacent to the detection region, wherein the one or more muon detection sensors of the first array measure positions and directions of muons passing through the first array to the detection region; a second detection unit including a second array of one or more muon detection sensors, the second detection unit positioned along a second side of the housing structure opposite the first side and adjacent to the detection region and at a fixed distance from the first detection unit, wherein the one or more muon detection sensors of the second array measure positions and directions of the muons passing from the detection region through the second array; a processing unit to receive data of the measured positions and directions from the first and second arrays of one or more muon detection sensors, the processing unit configured to analyze scattering behaviors of the muons caused by scattering of the muons in materials of the storage containers within the detection region to obtain a tomographic profile or spatial distribution of scattering centers within the detection region; and one or more fiducial markers formed of a known material and placed at known positions along a travel path of a positionally-aligned pair of detection sensors of the first and the second arrays, wherein the processing unit receives calibration data of the measured positions and directions of the muons passing through

the known material of the fiducial marker to enable identification of a false positive or a false negative in the analyzed scattering behaviors of the muons.

In another aspect, a method of materials inspection in a storage facility using muon tomography, comprising: scanning a storage container stored in a storage facility using muon sensors to obtain muon tomography imaging data, the storage facility including housing structure having a first detection unit and a second detection unit positioned in a fixed alignment with respect to each other; moving the first detection unit and the second detection unit from a first position to a second position in the housing structure while maintain the fixed alignment between the first detection unit and the second detection unit; scanning a calibration marker of a known material located at a known position in the storage facility along a travel path of a positionally-aligned pair of muon sensors of the first and second detection units to obtain muon tomography imaging data; and determining, using a processing unit, the presence or lack of presence of a target material in the storage container based on the obtained muon tomography imaging data of the scanned storage container and the scanned calibration marker, wherein the imaging data of the scanned calibration marker includes receiving calibration data of the measured positions and directions of the muons having passed through the known material and identifying a false positive or a false negative in the analyzed scattering behaviors of the muons, wherein the first detection unit includes a first array of the muon sensors configured in a first plane and the second detection unit includes a second array of the muon sensors configured in a second plane parallel to the first plane, such that the muon sensors of the first array measure positions and directions of muons passing through the first array and the muon sensors of the second array measure positions and directions of the muons passing from the detection region through the second array, and wherein the processing unit receives data of the measured positions and directions from the muon sensors and analyzes muon scattering behaviors caused by scattering of the muons in materials of the storage container.

**[0006]** These and other features are described in greater detail in the drawings, the description and the claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0007]** FIG. 1A shows an illustrative diagram of an exemplary muon tomography materials inspection station for automotive vehicles.

**[0008]** FIG. 1B shows an illustrative diagram of a lower detection unit of the exemplary muon tomography materials inspection station.

**[0009]** FIG. 2 shows an illustrative diagram of an exemplary muon tomography materials inspection station for aircraft.

**[0010]** FIG. 3A shows an illustrative diagram of an exemplary muon tomography materials inspection station for a warehouse or storage facility.

**[0011]** FIG. 3B shows an illustrative diagram of another exemplary muon tomography materials inspection station for a warehouse or storage facility.

**[0012]** FIG. 3C shows an illustrative diagram of another exemplary muon tomography materials inspection station for a warehouse or storage facility.

**[0013]** Like reference symbols and designations in the various drawings indicate like elements.

## DETAILED DESCRIPTION

**[0014]** Cosmic ray tomography is a technique which exploits the multiple Coulomb

## CLAIMS

1. A system for muon tomography detection having movable muon detection sensors, comprising:

a first housing structure including a first array of one or more muon detection sensors, the first housing structure positioned along a first side adjacent to a detection region having a volume to contain a target object, wherein the one or more muon detection sensors of the first array measure positions and directions of muons passing through the first array to the detection region;

a second housing structure including a second array of one or more muon detection sensors, the second housing structure positioned along a second side opposite the first side and adjacent to the detection region and at a fixed height from the first housing structure, wherein the one or more muon detection sensors of the second array measure positions and directions of the muons passing from the detection region through the second array;

one or more support structures to position the first housing structure at the fixed height;

a motion mechanism engaged to the first and second arrays of one or more muon detection sensors to move the first and second arrays of one or more muon detection sensors at different positions while maintaining a relative position with respect to each other; ~~and~~

a processing unit to receive data of the measured positions and directions from the first and second arrays of one or more muon detection sensors, the processing unit configured to analyze scattering behaviors of the muons caused by scattering of the muons in materials of the target object within the detection region to obtain a tomographic profile or spatial distribution of scattering centers within the detection region; and

one or more fiducial markers formed of a known material and placed at known positions along a travel path of a positionally-aligned pair of detection sensors of the first and the second arrays, wherein the processing unit receives calibration data of the measured positions and directions of the muons passing through the known material of the fiducial marker to enable identification of a false positive or a false negative in the analyzed scattering behaviors of the muons.

2. The system of claim 1, wherein the target object includes one of a automotive vehicle, a train, an aerial vehicle, a sea vehicle, or a container capable of being transported by the automotive vehicle, the train, the aerial vehicle, or the sea vehicle.

3. The system of claim 1, further comprising:

one or more guide structures configured in the detection region to align the target object in a particular orientation or position in the detection region.

15. The system of claim 1, wherein the processing unit is in wired or wireless communication with the one or more muon detection sensors of the first array and the second array.

16. The system of claim 1, wherein the processing unit is located in a remote site from the components of the system.

17. The system of claim 1, wherein the system is integrated in a building or structural assembly such that the system is hidden from plain sight.

18. A vehicle inspection station having a built-in muon tomography inspection capability, comprising:

a housing structure structured to at least partially enclose a vehicle and allow the vehicle to move in and out of the housing structure, the housing structure including a detection region to contain the vehicle;

a first detection unit including a first array of one or more muon detection sensors, the first detection unit positioned along a first side of the housing structure adjacent to the detection region, wherein the one or more muon detection sensors of the first array measure positions and directions of muons passing through the first array to the detection region;

a second detection unit including a second array of one or more muon detection sensors, the second detection unit positioned along a second side of the housing structure opposite the first side and adjacent to the detection region and at a fixed distance from the first detection unit, wherein the one or more muon detection sensors of the second array measure positions and directions of the muons passing from the detection region through the second array;

a platform located in the detection region between the first and second detection units and configured to include a surface to receive and support a vehicle to be inspected, the platform including tracks or alignment marks for guiding the vehicle to a desired position on the platform to be inspected; ~~and~~

a processing unit to receive data of the measured positions and directions from the first and second arrays of one or more muon detection sensors, the processing unit configured to analyze scattering behaviors of the muons caused by scattering of the muons in materials of the vehicle within the detection region to obtain a tomographic profile or spatial distribution of scattering centers within the detection region; and

one or more fiducial markers formed of a known material and placed at known positions along a travel path of a positionally-aligned pair of detection sensors of the first and the second arrays, wherein the processing unit receives calibration data of the measured positions and directions of the muons passing through the known material of the fiducial marker to enable identification of a false positive or a false negative in the analyzed scattering behaviors of the muons.

first detection unit positioned along a first side of the housing structure adjacent to the detection region, wherein the one or more muon detection sensors of the first array measure positions and directions of muons passing through the first array to the detection region;

a second detection unit including a second array of one or more muon detection sensors, the second detection unit positioned along a second side of the housing structure opposite the first side and adjacent to the detection region and at a fixed distance from the first detection unit, wherein the one or more muon detection sensors of the second array measure positions and directions of the muons passing from the detection region through the second array; ~~and~~

a processing unit to receive data of the measured positions and directions from the first and second arrays of one or more muon detection sensors, the processing unit configured to analyze scattering behaviors of the muons caused by scattering of the muons in materials of the storage containers within the detection region to obtain a tomographic profile or spatial distribution of scattering centers within the detection region; and

one or more fiducial markers formed of a known material and placed at known positions along a travel path of a positionally-aligned pair of detection sensors of the first and the second arrays, wherein the processing unit receives calibration data of the measured positions and directions of the muons passing through the known material of the fiducial marker to enable identification of a false positive or a false negative in the analyzed scattering behaviors of the muons.

29. The warehouse of claim 28, wherein the first detection unit is configured above the ceiling or roof of the storage container inspection station, and the second detection unit is configured under the floor of the storage container inspection station.

30. The warehouse of claim 28, wherein the housing structure includes two walls substantially parallel, and the first detection unit and the second detection unit are configured in the two walls, respectively.

31. The warehouse of claim 28, further comprising:

a first transport device and a second transport device to enable movement of the first detection unit and the second detection unit, respectively, in unison and along a path in the housing structure, wherein the location of the detection region changes accordingly with the movement of the first detection unit and the second detection unit.

~~32. The warehouse of claim 31, further comprising:~~

~~a calibration marker formed of a known material and configured in the path, wherein the processing unit receives calibration data of the measured positions and directions of the muons passing through the known material of the calibration marker and the first and second arrays of one or more muon detection sensors.~~

~~33~~32. The warehouse of claim 31, further comprising:

a first position sensor coupled to the first detection unit and a second position sensor coupled to the second detection unit, wherein the first and second position sensors provide data on relative position between the first detection unit and the second detection unit.

~~34~~33. The warehouse of claim 28, wherein the processing unit produces an image based on the tomographic profile or the spatial distribution.

~~35~~34. The warehouse of claim 28, wherein the processing unit is in wired or wireless communication with the one or more muon detection sensors of the first array and the second array.

~~36~~35. The warehouse of claim 28, wherein the processing unit is located in a remote site from the housing structure.

~~37~~36. A method of materials inspection in a storage facility using muon tomography, comprising:

scanning a storage container stored in a storage facility using muon sensors to obtain muon tomography imaging data, the storage facility including housing structure having a first detection unit and a second detection unit positioned in a fixed alignment with respect to each other;

moving the first detection unit and the second detection unit from a first position to a second position in the housing structure while maintain the fixed alignment between the first detection unit and the second detection unit;

scanning a calibration marker of a known material located at a known position in the storage facility along a travel path of a positionally-aligned pair of muon sensors of the first and second detection units ~~using muon sensors~~ to obtain muon tomography imaging data; and

determining, using a processing unit, the presence or lack of presence of a target material in the storage container based on the obtained muon tomography imaging data of the scanned storage container and the scanned calibration marker, wherein the imaging data of the scanned calibration marker includes receiving calibration data of the measured positions and directions of the muons having passed through the known material and identifying a false positive or a false negative in the analyzed scattering behaviors of the muons,

wherein the first detection unit includes a first array of the muon sensors configured in a first plane and the second detection unit includes a second array of the muon sensors configured in a second plane parallel to the first plane, such that the muon sensors of the first array measure positions and directions of muons passing through the first array and the muon sensors of the