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Office of Commercialization, P.O. Box 641060, Pullman, WA 99164 (US).

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(74) Agent: FRANK, Louis C. et al.; Saliwanchik, Lloyd & Eisenschenk, P.O. Box 142950, Gainesville, FL 32614-2950 (US).

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(71) Applicants: THE TAXAS A&M UNIVERSITY SYSTEM [US/US]; 3369 TAMU, Office of Technology Commercialization, College Station, TX 77843 (US). WASHINGTON STATE UNIVERSITY [US/US]; Office of Commercialization, P.O. Box 641060, Pullman, WA 99164 (US).

(72) Inventors: MORGAN, Cristine; c/o Texas A&M University, 370 Olsen Boulevard, College Station, TX 77843 (US). GE, Yufeng; c/o Texas A&M University, 370 Olsen Boulevard, College Station, TX 77843 (US). BROWN, David; c/o Washington State University, Office of Commercialization, P.O. Box 641060, Pullman, WA 99164 (US). BRICK-LEMYER, Ross; c/o Washington State University, Of-

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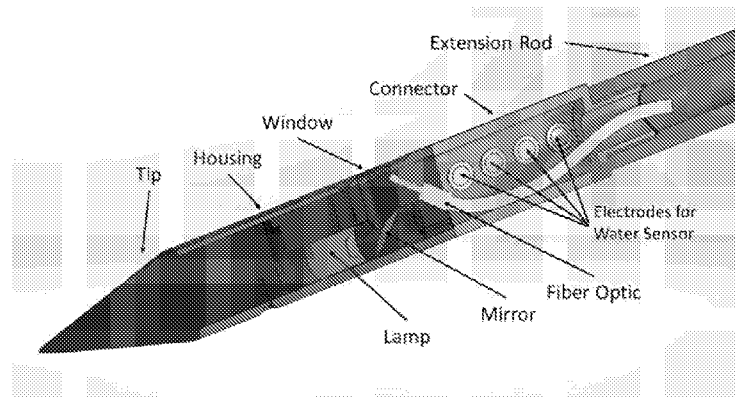


FIG. 2

(57) Abstract: Soil penetrometers capable of measuring soil reflectance along the direction of insertion of the penetrometer are provided. The penetrometer can house an array of sensors, such as, for example, a Vis-NIR reflectance sensor, a load cell, a displacement sensor, and a moisture sensor. The reflectance data collected using the penetrometer can allow the interpretation and quantification of soil constituents and contaminants at high vertical resolution, such as 3 cm or more.



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DESCRIPTION

VIS-NIR EQUIPPED SOIL PENETROMETER

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CROSS-REFERENCE TO RELATED APPLICATION

The present application claims the benefit of U.S. Provisional Application Serial No. 62/353,716, filed June 23, 2016, which is incorporated herein by reference in its entirety, including any figures, tables, and drawings.

10

GOVERNMENT SUPPORT

The subject invention was made with government support under 68-7482-2-39 awarded by USDA Natural Resources Conservation Services (NRCS), USDA-NIFA Award No. 2011-67003-30341, and under DE-FC26-05NT42587 awarded by U.S. Department of Energy National Energy Technology Laboratory to Dr. David Joseph Brown et al. The government has certain rights in the invention.

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BACKGROUND OF INVENTION

Visible and near infrared reflectance spectroscopy (Vis-NIR) is widely used as a rapid and cost-effective technique for quantitative analysis of many soil properties. However, existing Vis-NIR-based instruments for *in situ* characterization of soil have many limitations and face challenges when attempting to obtain high resolution spatial and temporal soil data intended for precision agriculture, soil survey and mapping, land resource management, and soil modeling.

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BRIEF SUMMARY

The subject invention provides soil penetrometers capable of measuring soil reflectance in the direction of insertion of the penetrometer, as well as methods of fabricating and using the same. The penetrometer can house a sensor or an array of sensors, including, for example, one or more visible and near infrared reflectance spectroscopy Vis-NIR reflectance sensors, load cells, displacement sensors, and/or moisture sensors. The reflectance data collected using the penetrometer provided herein

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allow the interpretation and quantification of soil constituents and contaminants at higher vertical resolution (e.g., approximately 3 cm or more) than conventional penetrometers.

In an embodiment, a soil penetrometer can include an optical module enclosed in a housing (e.g., a tubular housing), which is connected to a tip (e.g., a conical tip) at one end and a connector (e.g., a tubular connector) at the opposite end. The connector (e.g.,
5 tubular connector) can be connected to an extension rod. The housing (e.g., tubular housing) can further include a transparent window, which can include or be made of, for example, sapphire. The optical module can include a mirror, a light-emitting device, and/or a fiber optic sensor, which can be fixed in the vicinity of, and at a pre-determined
10 angle with respect to, the plane parallel to the transparent window.

In a further embodiment, the connector (e.g., tubular connector) can enclose one or more sensing devices. The connector can be connected to the housing at one end and detachably connected to the extension rod at the opposite end.

In yet a further embodiment, the extension rod can be detachably connected to
15 another device or a combination of devices at the end opposite to the connector.

The soil penetrometer can be plugged into an existing Vis-NIR spectrometer that is capable of quantifying soil constituents. In some embodiments, the penetrometer with the spectrometer attached is field-portable.

Advantageously, the subject invention enhances the ability to collect *in situ* high
20 resolution reflectance data for soil constituent interpretation and quantification and can be widely used by researchers in fields such as natural resource management, hydrologic modeling, soil mapping, and precision agriculture.

BRIEF DESCRIPTION OF THE DRAWINGS

25 **Figure 1** shows a schematic view of a penetrometer according to an embodiment of the subject invention.

Figure 2 shows a cross-sectional view of a penetrometer according to an embodiment of the subject invention having a moisture sensor enclosed in the connector.

Figure 3 shows a cross-sectional view of a penetrometer according to an
30 embodiment of the subject invention, indicating the path of light within the optical module.

Figure 4 shows a schematic view of an external portion of a penetrometer according to an embodiment of the subject invention.

Figure 5A shows a schematic of a penetrometer according to an embodiment of the subject invention.

5 **Figure 5B** shows a schematic of a penetrometer according to an embodiment of the subject invention.

Figures 6A and 6B are soil scans acquired by a penetrometer according to an embodiment of the subject invention, in comparison with a standard mug lamp accessory. The scans are very close to each other for all four representative samples, indicating good
10 performance of the penetrometer.

Figure 7A shows clay Vis-NIR prediction results for selected samples. The model was calibrated by scans obtained with the mug lamp used for the data shown in Figures 6A and 6B.

Figure 7B shows organic carb Vis-NIR prediction results for selected samples.
15 The model was calibrated by the scans obtained with the mug lamp used for the data shown in Figures 6A and 6B. For both Figures 7A and 7B, the squares are the scans acquired by the ASDi mug lamp, and the crosses are the scans by the penetrometer according to an embodiment of the subject invention.

Figure 8 shows the principal component loadings for the EPO for soils from
20 Texas, Australia, and Brazil (left to right).

Figure 9 shows a image of a penetrometer according to an embodiment of the subject invention connected to a Vis-NIR spectrometer and mounted on a soil probe truck during a field test.

Figure 10 is a schematic illustrating a Vis-NIR signal correction process.

25 **Figure 11** shows Vis-NIR predictions of clay content using dry-ground spectral libraries made on dry-ground soil. Using the same library, predictions were made on intact and moist soil with and without EPO, respectively.

Figure 12A shows a P-matrix generated on soil from Texas.

Figure 12B shows a P-matrix generated on soil from Australia.

30 **Figure 13A** shows predicted clay content for data projected with both the Texas and the Australia P-matrices of Figures 12A and 12B.

Figure 13B shows the predicted organic carbon content for data projected with both the Texas and the Australia P-matrices of Figures 12A and 12B.

Figure 14 shows a schematic view of a tubular housing of a penetrometer according to an embodiment of the subject invention.

5 **Figure 15** shows a schematic view of an optical module unit of a penetrometer according to an embodiment of the subject invention.

Figure 16 shows a schematic view of a conical tip of a penetrometer according to an embodiment of the subject invention.

10 **Figure 17** shows a schematic view of a connector of a penetrometer according to an embodiment of the subject invention.

Figure 18 shows a schematic view of an extension rod of a penetrometer according to an embodiment of the subject invention.

DETAILED DISCLOSURE

15 The subject invention provides soil penetrometers capable of measuring soil reflectance in the direction of insertion of the penetrometer, as well as methods of fabricating and using the same. The penetrometer can house a sensor or an array of sensors, including, for example, one or more visible and near infrared reflectance spectroscopy Vis-NIR reflectance sensors, load cells, displacement sensors, and/or
20 moisture sensors. The reflectance data collected using the penetrometer provided herein allow the interpretation and quantification of soil constituents and contaminants at higher vertical resolution (e.g., approximately 3 cm or more) than conventional penetrometers.

 In many embodiments, the soil penetrometer can include an optical module enclosed in a housing (e.g., a tubular housing), which is connected to a tip (e.g., a conical
25 tip) at one end and a connector (e.g., a tubular connector) at the opposite end. The connector (e.g., tubular connector) can be further connected to an extension rod (as shown in Figures 1 and 4). The (tubular) housing can further include a transparent window, which can be a sapphire window, though embodiments are not limited thereto. The window can be designed to facilitate transmission of light between the optical module and
30 the soil sample. The window (e.g., sapphire window) can measure approximately 0.5 inch in diameter and can be built into the wall of the (tubular) housing.

In an embodiment, the outer diameter of a tubular housing can be approximately 1.25 inch, and the inner diameter can be approximately 1.0 inch (as shown in Figure 14).

In a specific embodiment, the body of the (tubular) housing can include or be made from stainless steel.

5 In many embodiments, the optical module can include a mirror, a light-emitting device, and/or a fiber optic sensor, which can be fixed at a pre-determined angle with respect to the plane parallel to the transparent window (as shown in Figure 2) (that is, the plane parallel to the flat surface of the window). In an embodiment, the angle between fiber optic sensor and the plane parallel to the transparent window is between about 40
10 degrees to about 55 degrees. In an embodiment, the optical module can be enclosed in a casing (e.g., an aluminum casing) having a diameter that measures approximately 1.0 inch (as shown in Figure 15).

According to some embodiments of the subject invention, the mechanism of signal generation and detection by which the soil sample is analyzed can be described by the
15 following process (Figure 3). Light is first generated by the light-emitting device such as, for example, a lamp, a light-emitting diode (LED), or the like. The light is then reflected by the mirror and subsequently transmitted through the window (e.g., sapphire window). After the light interacts with the soil, the reflected signal is transmitted back through the window and subsequently detected by the fiber optic sensor. In a specific embodiment,
20 the fiber optic sensor is connected to a Vis-NIR spectrometer of choice as well as any other additional devices and components needed to acquire spectral scans such as, for example, data logging and power supply equipment. In certain embodiments, the wiring between the fiber optic sensor and the spectrometer can be enclosed within the cavity of the penetrometer.

25 Artisans skilled in the pertinent field would appreciate that the geometric arrangement of the fiber optic sensor with respect to the plane parallel to the window (e.g., sapphire window) matches that of an industry-standard tool for collecting soil spectra under laboratory conditions. A non-limiting example of the tool is a mug lamp, such as the one manufactured by the Analytical Spectral Devices Inc. Advantageously, depending
30 upon the specific spectrometer employed and the signal-to-noise ratio desired, different geometric arrangements of the optical module can be accommodated by embodiments of the penetrometer of the subject invention, making it customizable.

In many embodiments, the soil penetrometer can be plugged into an existing Vis-NIR spectrometer that is capable of quantifying soil constituents in the laboratory. In a specific embodiment, the spectrometer employed herein can collect soil reflectance data in a range of between approximately 350 nm and approximately 2500 nm.

5 In some embodiments, the penetrometer is equipped with a multi-sensor platform comprising devices for measuring one or more parameters including, but not limited to, time-domain reflectometry (TDR), penetration resistance, displacement, and load.

In some embodiments, the penetrometer is made field-portable by being connected to devices including but not limited to trucks, all-terrain vehicles, and tractor-mounted
10 hydraulic soil probes (Figure 9).

In many embodiments, the tip (e.g., conical tip) includes stainless steel and/or can be the first component of the penetrometer to be inserted into the soil sample. In some embodiments, the tip is hollow. In a specific embodiment, the diameter of the base of the (conical) tip measures approximately 1.25 inch, and the portion of the tip that connects
15 with the tubular housing measures approximately 1.0 inch in diameter (Figure 16). Advantageously, additional components and/or sensing devices can be attached to and/or enclosed in the tip with non-limiting examples including a capacitance sensor used for detecting degree of soil moisture.

In some embodiments, the connector (e.g., tubular connector) can enclose one or
20 more sensing devices. Non-limiting examples of sensing devices include an auxiliary moisture sensor including electrodes that measure the electrical resistivity, and thus the moisture content, of the soil sample. In a particular embodiment, electrodes measuring resistivity can be attached to the wall of the connector and exposed to the surrounding soil sample. In many embodiments, the connector can be attached to the housing (e.g., tubular
25 housing) at one end, preferably by welding, and detachably and securely connected to the extension rod at the opposite end. In a particular embodiment, the end of the connector that mates with the extension rod is machine-threaded.

In an embodiment, the outer diameter of the connector measures approximately 1.25 inch, and the inner diameter measures approximately 0.95 inch. The threaded portion
30 of the connector that mates with the extension rod can measure approximately 0.55 inch in diameter (Figure 17).

In many embodiments, the extension rod (e.g., tubular extension rod) can be detachably connected to another device or a combination of devices at the end opposite to the connector. The ends of the extension rod can be threaded in order to facilitate easy removal of the penetrometer and other devices therefrom. In an embodiment, the extension rod can serve to attach the penetrometer to existing hydraulic soil sampling equipment that is optionally field-portable. In a further embodiment, a load cell can be threaded to the end of the extension rod opposite the penetrometer.

In an embodiment, the extension rod can measure approximately 1.125 inch in outer diameter and approximately 0.625 inch in inner diameter, and can be uniform in size throughout its length (Figure 18).

The extension rod can include or be made of, for example, stainless steel, though embodiments are not limited thereto.

In many embodiments, a method of measuring soil reflectance can include using a soil Vis-NIR penetrometer as described herein for its intended purpose. In some embodiments, spectra can be collected at discrete depth intervals. During a discrete depth scan, the penetrometer is inserted into the soil to a specified depth at which a Vis-NIR spectrum is collected. In alternative embodiments, spectra can be collected continuously throughout the penetrometer's insertion. During continuous scans, the penetrometer is slowly inserted into the soil without stopping at any defined depth. Throughout the insertion, Vis-NIR spectra are collected as frequently as the instrumentation allows. In further embodiments, scans can be collected in intervals of approximately 2 to approximately 5 seconds (whether for continuous scan or during collection at discrete depth intervals).

The subject invention includes, but is not limited to, the following exemplified embodiments.

Embodiment 1. A soil penetrometer, comprising:
a conical tip capable of penetrating into a soil sample;
a tubular housing connected to the conical tip at one end;
a tubular connector attached to the tubular housing at one end; and

a tubular extension rod capable of being detachably connected to the connector at the end opposite to the tubular housing and detachably connected to another device or a combination of devices at the end opposite to the connector,

wherein the tubular housing comprises:

- 5 a transparent window built into the wall thereof, and
 an optical module comprising a light-emitting device, a mirror capable of reflecting light (and/or configured to reflect light) generated by the light-emitting device, and a fiber optic sensor, wherein the sensor is positioned in the vicinity of the transparent window to receive signals reflected by the soil sample and transmit the signals to a spectrometer.
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Embodiment 2. The penetrometer according to embodiment 1, wherein the connector encloses one or more sensing devices.

- 15 Embodiment 3. The penetrometer according to any of embodiments 1-2, comprising a moisture sensor enclosed in the connector.

Embodiment 4. The penetrometer according to any of embodiments 1-3, wherein the light-emitting device is a lamp.

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Embodiment 5. The penetrometer according to any of embodiments 1-4, wherein the transparent window comprises sapphire.

- Embodiment 6. The penetrometer according to any of embodiments 1-5, wherein the detecting end of the optic fiber is positioned with respect to the plane parallel to the transparent window at an angle between about 40 degrees and about 55 degrees that allows optimal spectral collection by the optic fiber.
- 25

- Embodiment 7. The penetrometer according to any of embodiments 1-6, wherein the end of the optic fiber opposite to the detecting end extends through the connector and the extension rod and is connected to a Vis-NIR spectrometer.
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Embodiment 8. The penetrometer according to any of embodiments 1-7, wherein the conical tip is hollow.

Embodiment 9. The penetrometer according to any of embodiments 1-8,
5 capable of accommodating (or actually accommodates) a sensing device or a combination of devices (e.g., inside the tip, which may be hollow).

Embodiment 10. The penetrometer according to embodiments 9, wherein the
10 sensing device is a capacitance sensor.

Embodiment 11. The penetrometer according to any of embodiments 1-10, wherein the optical module is enclosed in an aluminum housing (which may be the tubular housing or a second housing within the tubular housing).

15 Embodiment 12. The penetrometer according to any of embodiments 1-11, wherein the conical tip, the connector, and the extension rod each comprises stainless steel.

Embodiment 13. The penetrometer according to any of embodiments 1-12,
20 wherein the end of the extension rod opposite to the connector is connected to a device selected from soil sampling equipment, soil coring equipment, a load cell, a displacement sensor, a time-domain reflectometer, and a combination thereof.

Embodiment 14. The penetrometer according to any of embodiments 1-13,
25 wherein the optical fiber is configured in different geometries with respect to the plane parallel to the transparent window to obtain different signal-to-noise ratios.

Embodiment 15. The penetrometer according to any of embodiments 1-14,
30 which is field-portable.

Embodiment 16. A method of measuring soil reflectance, comprising:
providing the soil penetrometer according to any of embodiments 1-15;

providing a soil sample; and

measuring the soil reflectance at a given depth within the sample using the soil penetrometer.

5 Embodiment 17. The method according to embodiment 16, wherein the soil reflectance is measured continuously as the penetrometer is inserted into the soil sample.

 Embodiment 18. The method according to embodiment 16, wherein the soil reflectance is measured at discrete depths as the penetrometer is inserted into the soil
10 sample.

 Embodiment 19. A method of measuring soil reflectance, comprising:
providing a soil penetrometer, comprising:

 a conical tip capable of penetrating into a soil sample, the tip comprising at
15 least one sensing device;

 a tubular housing connected to the conical tip at one end, comprising a transparent window built into the wall thereof and an optical module comprising a light-emitting device, a mirror capable of reflecting light (and/or configured to reflect light) generated by the light-emitting device, and a fiber optic sensor,
20 wherein the sensor is positioned in the vicinity of the transparent window to receive signals reflected by the soil sample and transmits the signal to a Vis-NIR spectrometer;

 a tubular connector attached to the tubular housing at one end, the connector comprising a built-in moisture sensor; and

25 a tubular extension rod capable of being detachably connected to the connector at the end opposite to the tubular housing and detachably connected to another device or a combination of devices selected from soil sampling equipment, soil coring equipment, a load cell, a displacement sensor, and a time-domain reflectometer, at the end opposite to the connector;

30 providing a soil sample; and

measuring the soil reflectance at a given depth within the sample.

Embodiment 20. The method according to embodiment 19, wherein the soil reflectance is measured continuously as the penetrometer is inserted into the soil sample.

Embodiment 21. The method according to embodiment 19, wherein the soil reflectance is measured at discrete depths as the penetrometer is inserted into the soil sample.

Embodiment 22. A Vis-NIR soil penetrometer, comprising:
a conical tip capable of penetrating into a soil sample;
a tubular housing connected to the conical tip at one end;
a tubular connector attached to the tubular housing at one end, the connector comprising a built-in moisture sensor; and
a tubular extension rod capable of being detachably connected to the connector at the end opposite to the tubular housing and detachably connected to another device or a combination of devices selected from soil sampling equipment, soil coring equipment, a load cell, a displacement sensor, and a time-domain reflectometer, at the end opposite to the connector,
wherein the tubular housing comprises:
a transparent window built into the wall thereof; and
an optical module comprising a light-emitting device, a mirror capable of reflecting light (and/or configured to reflect light) generated by the light-emitting device, and a fiber optic sensor, wherein the sensor is positioned in the vicinity of the transparent window to receive signals reflected by the soil sample and transmits the signal to a Vis-NIR spectrometer.

Embodiment 23. The penetrometer according to embodiment 22, which is field-portable.

A greater understanding of the present invention and of its many advantages may be had from the following examples, given by way of illustration. The following examples are illustrative of some of the methods, applications, embodiments and variants of the present invention. They are, of course, not to be considered as limiting the

invention. Numerous changes and modifications can be made with respect to the invention.

EXAMPLE 1

5 To assess the functionality of a penetrometer of the subject invention (as shown in Figures 5A and 5B), spectral scans of four representative soil samples were analyzed and compared with the scans obtained using a standard mug lamp manufactured by Analytical Spectral Devices Inc. As shown in Figures 6A and 6B, the penetrometer demonstrated similar a spectral profile as the mug lamp, confirming its effectiveness in
10 measuring soil reflectance. Further, measured Vis-NIR clay and organic carbon content in 11 selected samples were compared with predicted values using Travis Waiser's Central Texas dataset and demonstrated in Figures 7A and 7B.

EXAMPLE 2

15 *In situ* Vis-NIR scans collected using a penetrometer disclosed herein can also be used to predict clay content of moist, intact soil samples using dry-ground sample spectral libraries with the help of a correction algorithm termed the external parameter orthogonalization (EPO). Due to the presence of water and soil heterogeneity, spectra collected *in situ* under moist conditions are distorted relative to the same soil sample
20 collected in dry-ground state. It was found that EPO could remove these distortions multiplying intact spectra with a projection matrix, or P-matrix (Figure 10). These results showed that the EPO can remove the effect of water content and soil heterogeneity from Vis-NIR spectra collected on intact soil cores. Applying EPO to Vis-NIR spectra collected using the penetrometer provided herein allows one to predict clay and organic
25 carbon content of intact or *in situ* soil using dry ground spectral libraries for evaluation of soil properties in the field (Figure 11).

The interchangeability of P-matrices developed on spectra from Texas and Australia was also tested (Figures 12A and 12B, respectively). The results showed that the two matrices were interchangeable providing strong evidence for the existence of a
30 universal P-matrix, which could potentially allow the estimation of only one P-matrix for EPO correction using any spectral library.

Testing of the EPO on soils from outside Texas was carried out and included tests of the EPO on Australian soils and Brazilian soils. Tests on Brazilian soils were conducted in conjunction with the University of São Paulo, Brazil. The results suggested that clay mineralogy affects the structure of the EPO transformation. Smectitic soils, (i.e., Texas and Australian soils), showed peaks in the EPO at approximately 2030 nm, whereas the kaolanitic samples from Brazil showed peaks at approximately 1930 nm (Figure 8, where left to right are Texas, Australia, and Brazil as depicted in Figure 8). These results suggest the EPO is transferable between soils of similar mineralogy but is not effective on soils of novel mineralogy.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application.

All patents, patent applications, provisional applications, and publications referred to or cited herein (including those in the “References” section) are incorporated by reference in their entirety, including all figures and tables, to the extent they are not inconsistent with the explicit teachings of this specification.

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Image from Veris Technologies e.g. Christy, 2008; Brickleyer and Brown 2010 Waiser et al. 2007 (VisNIR for Proximal Sensing PPT slide)

Wilke, 2008 (Coefficient of Linear Extensibility PPT slide)

CLAIMS

We claim:

1. A soil penetrometer, comprising:
 - a conical tip capable of penetrating into a soil sample;
 - a tubular housing connected to the conical tip at one end;
 - a tubular connector attached to the tubular housing at one end; and
 - a tubular extension rod capable of being detachably connected to the connector at the end opposite to the tubular housing and detachably connected to another device or a combination of devices at the end opposite to the connector,wherein the tubular housing comprises:
 - a transparent window built into the wall thereof; and
 - an optical module comprising a light-emitting device, a mirror capable of reflecting light generated by the light-emitting device, and a fiber optic sensor,wherein the sensor is positioned in the vicinity of the transparent window to receive signals reflected by the soil sample and transmits the signal to a spectrometer.
2. The penetrometer according to claim 1, wherein the connector encloses one or more sensing devices.
3. The penetrometer according to claim 2, comprising a moisture sensor enclosed in the connector.
4. The penetrometer according to claim 1, wherein the light-emitting device is a lamp.
5. The penetrometer according to claim 1, wherein the transparent window comprises sapphire.
6. The penetrometer according to claim 1, wherein the detecting end of the optic fiber is positioned with respect to the plane parallel to the transparent window at an angle

between about 40 degrees and about 55 degrees that allows optimal spectral collection by the optic fiber.

7. The penetrometer according to claim 6, wherein the end of the optic fiber opposite to the detecting end extends through the connector and the extension rod and is connected to a Vis-NIR spectrometer.

8. The penetrometer according to claim 1, wherein the conical tip is hollow.

9. The penetrometer according to claim 8, wherein the hollow conical tip accommodates a sensing device or a combination of devices therein.

10. The penetrometer according to claim 9, wherein the sensing device is a capacitance sensor.

11. The penetrometer according to claim 1, wherein the optical module is enclosed in the tubular housing, and the tubular housing comprises aluminum.

12. The penetrometer according to claim 1, wherein the conical tip, the tubular housing, the connector, and the extension rod each comprises stainless steel.

13. The penetrometer according to claim 1, wherein the end of the extension rod opposite to the connector is connected to a device selected from soil sampling equipment, soil coring equipment, a load cell, a displacement sensor, a time-domain reflectometer, and a combination thereof.

14. The penetrometer according to claim 1, wherein the optical fiber is configured in different geometries with respect to the plane parallel to the transparent window to obtain different signal-to-noise ratios.

15. The penetrometer according to claim 1, which is field-portable.

16. A method of measuring soil reflectance, comprising:

providing a soil penetrometer, comprising:

a conical tip capable of penetrating into a soil sample, the tip comprising at least one sensing device ;

a tubular housing connected to the conical tip at one end;

a tubular connector attached to the tubular housing at one end, the connector comprising a built-in moisture sensor; and

a tubular extension rod capable of being detachably connected to the connector at the end opposite to the tubular housing and detachably connected to another device or a combination of devices selected from soil sampling equipment, soil coring equipment, a load cell, a displacement sensor, and a time-domain reflectometer, at the end opposite to the connector,

wherein the tubular housing comprises:

a transparent window built into the wall thereof; and

an optical module comprising a light-emitting device, a mirror capable of reflecting light generated by the light-emitting device, and a fiber optic sensor, wherein the sensor is positioned in the vicinity of the transparent window to receive signals reflected by the soil sample and transmits the signal to a Vis-NIR spectrometer;

providing a soil sample; and

measuring the soil reflectance at a given depth within the sample.

17. The method according to claim 16, wherein the soil reflectance is measured continuously as the penetrometer is inserted into the soil sample.

18. The method according to claim 16, wherein the soil reflectance is measured at discrete depths as the penetrometer is inserted into the soil sample.

19. A Vis-NIR soil penetrometer, comprising:

a conical tip capable of penetrating into a soil sample, the tip comprising at least one sensing device ;

a tubular housing connected to the conical tip at one end;

a tubular connector attached to the tubular housing at one end, the connector comprising a built-in moisture sensor; and

a tubular extension rod capable of being detachably connected to the connector at the end opposite to the tubular housing and detachably connected to another device or a combination of devices selected from soil sampling equipment, soil coring equipment, a load cell, a displacement sensor, and a time-domain reflectometer, at the end opposite to the connector,

wherein the tubular housing comprises:

a transparent window built into the wall thereof; and

an optical module comprising a light-emitting device, a mirror capable of reflecting light generated by the light-emitting device, and a fiber optic sensor, wherein the sensor is positioned in the vicinity of the transparent window to receive signals reflected by the soil sample and transmits the signal to a Vis-NIR spectrometer.

20. The penetrometer according to claim 19, which is field-portable.

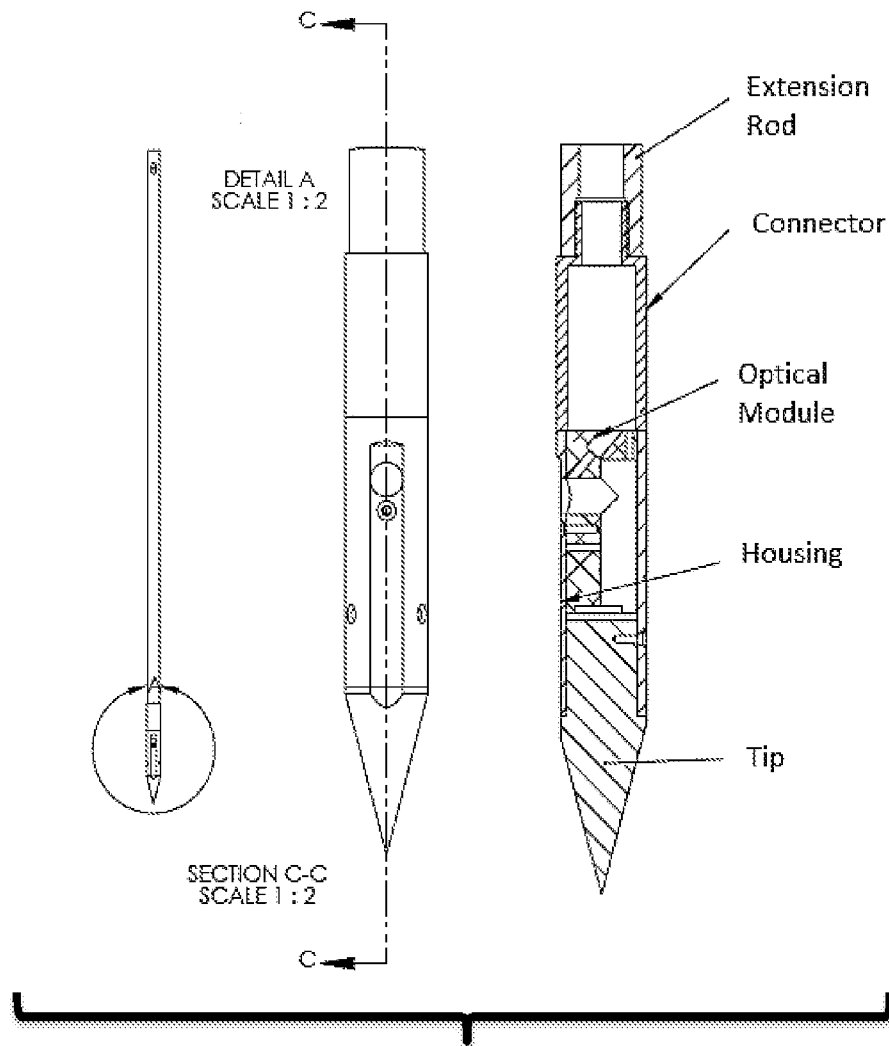


FIG. 1

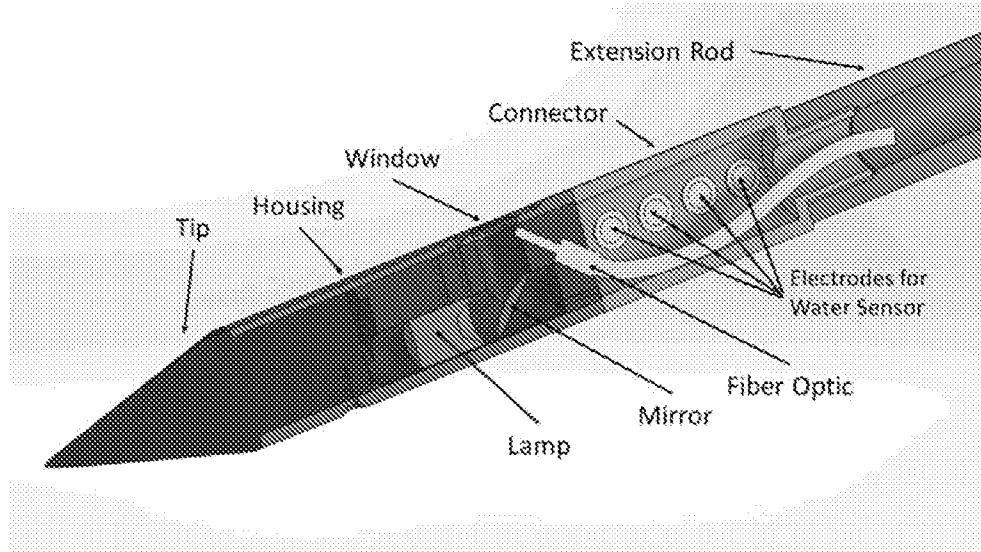


FIG. 2

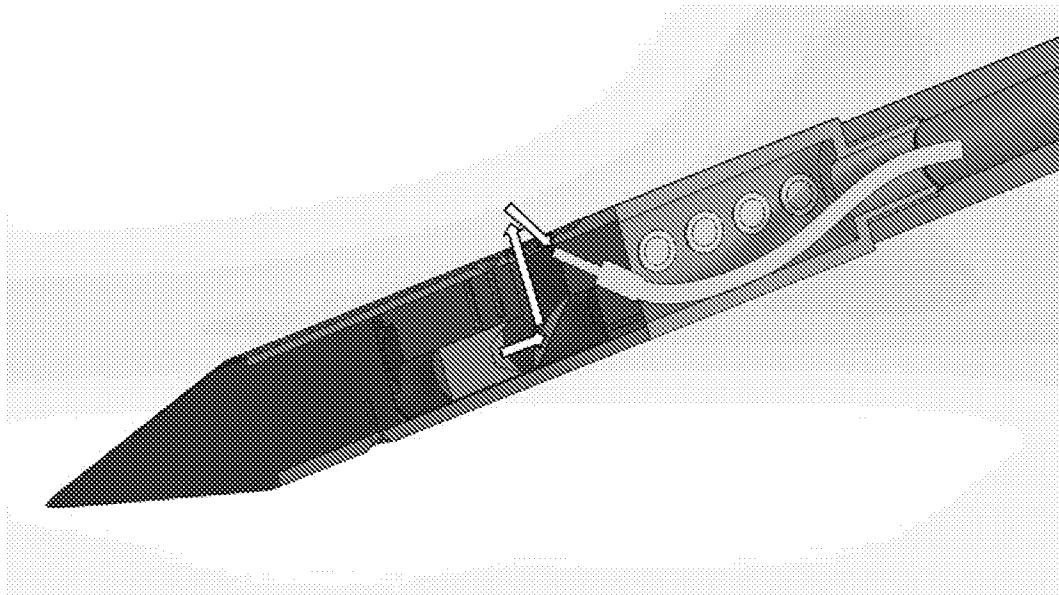


FIG. 3

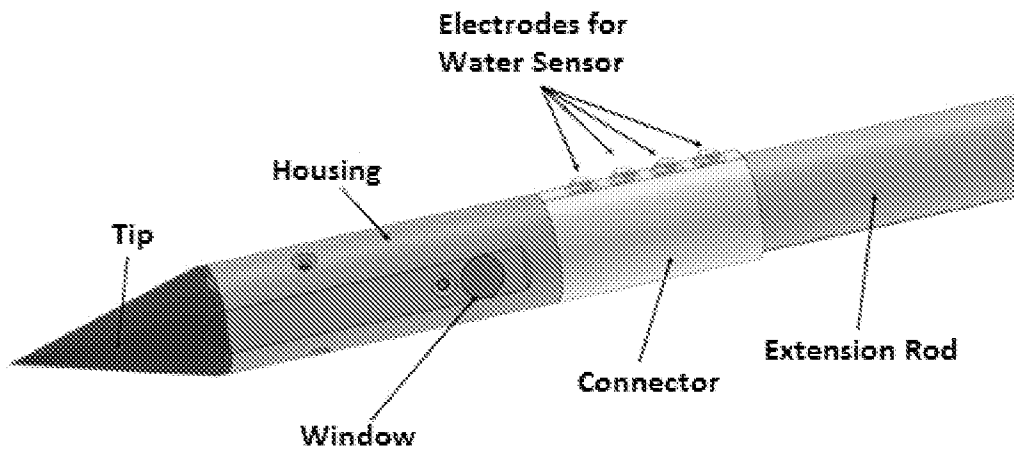


FIG. 4

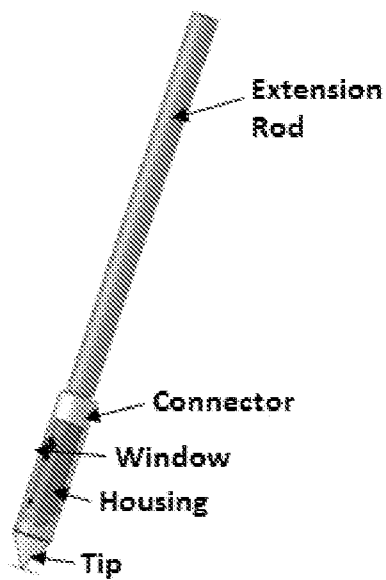


FIG. 5A

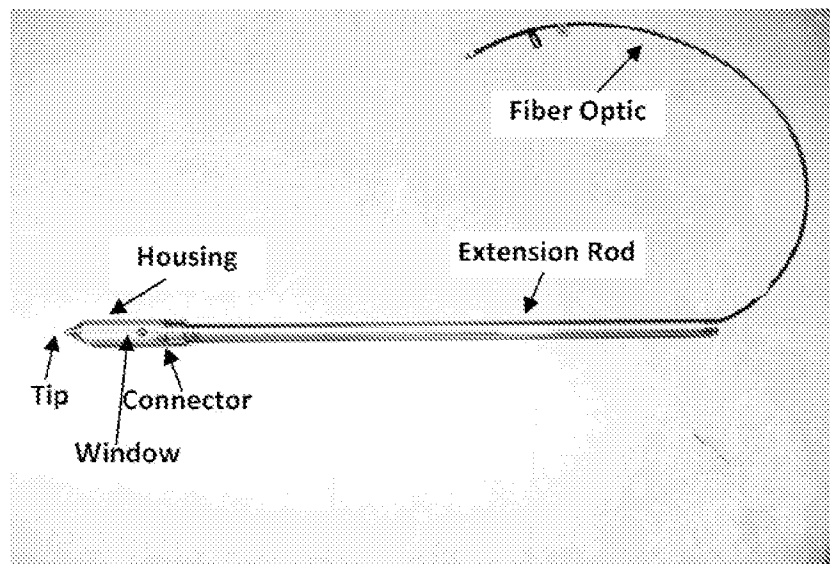


FIG. 5B

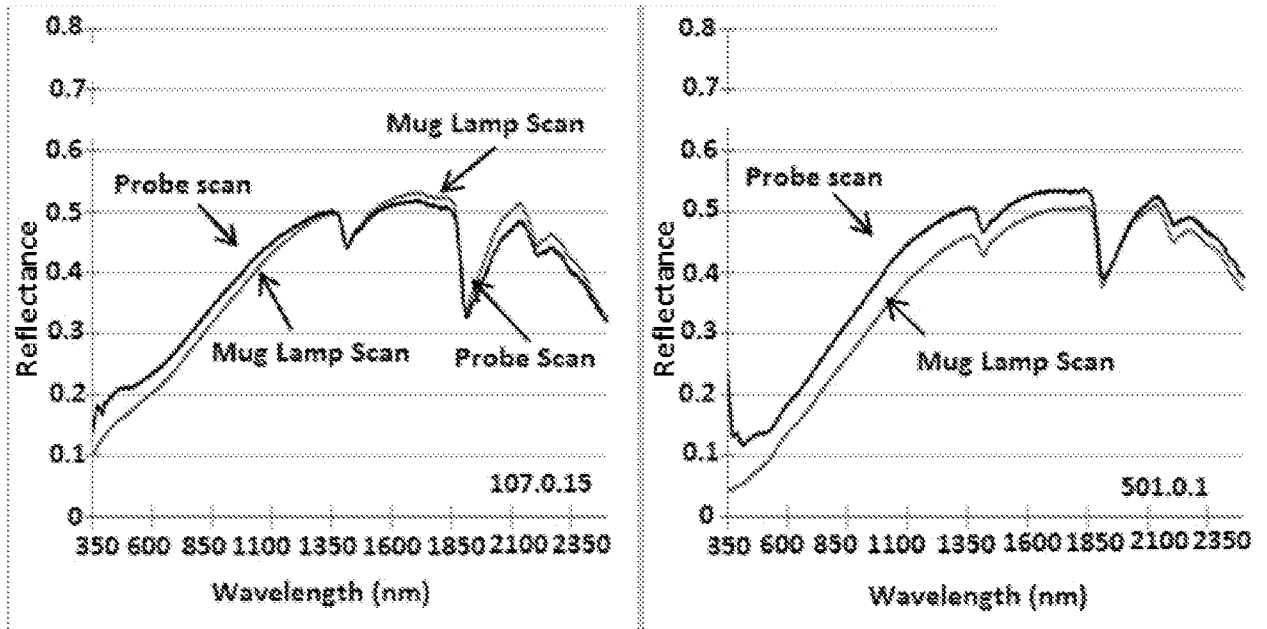


FIG. 6A

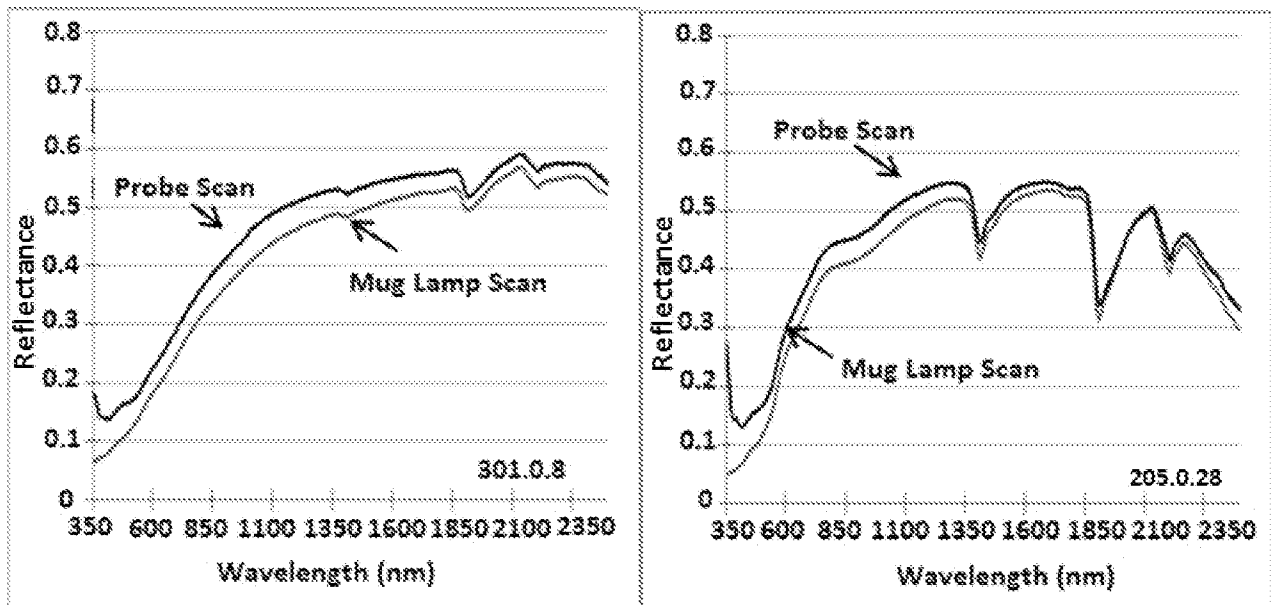


FIG. 6B

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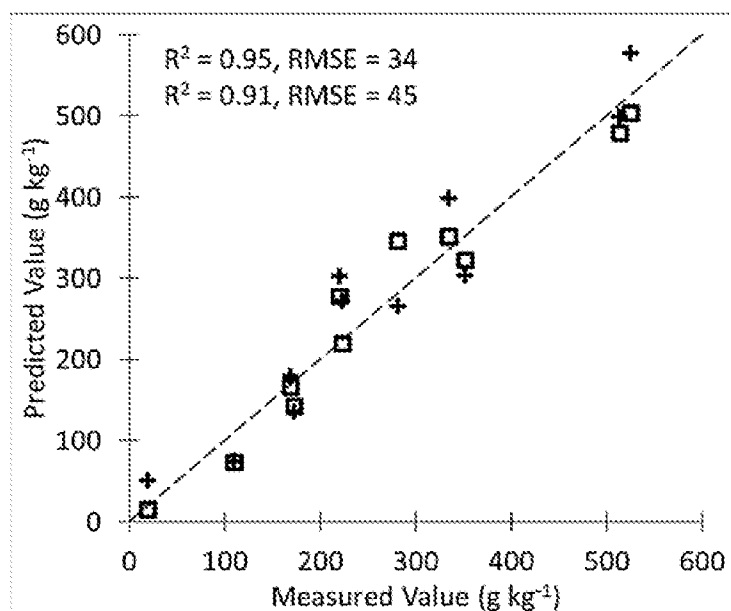


FIG. 7A

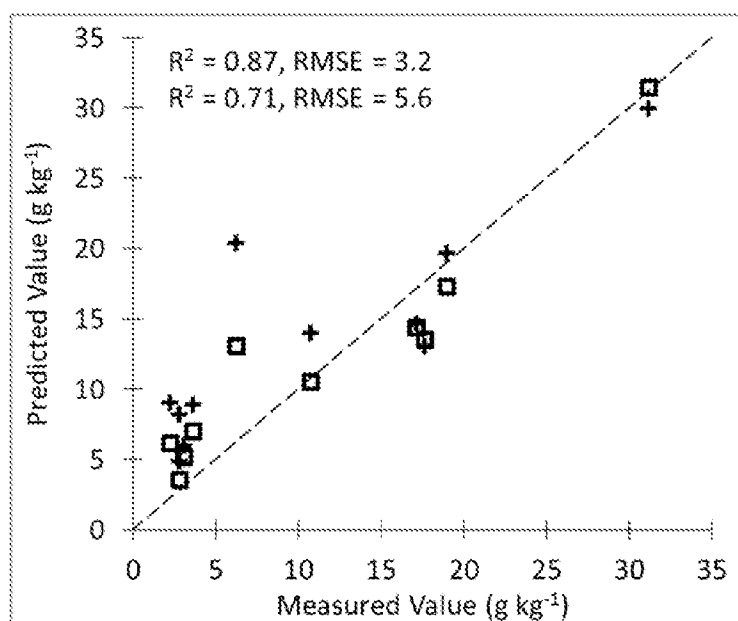


FIG. 7B

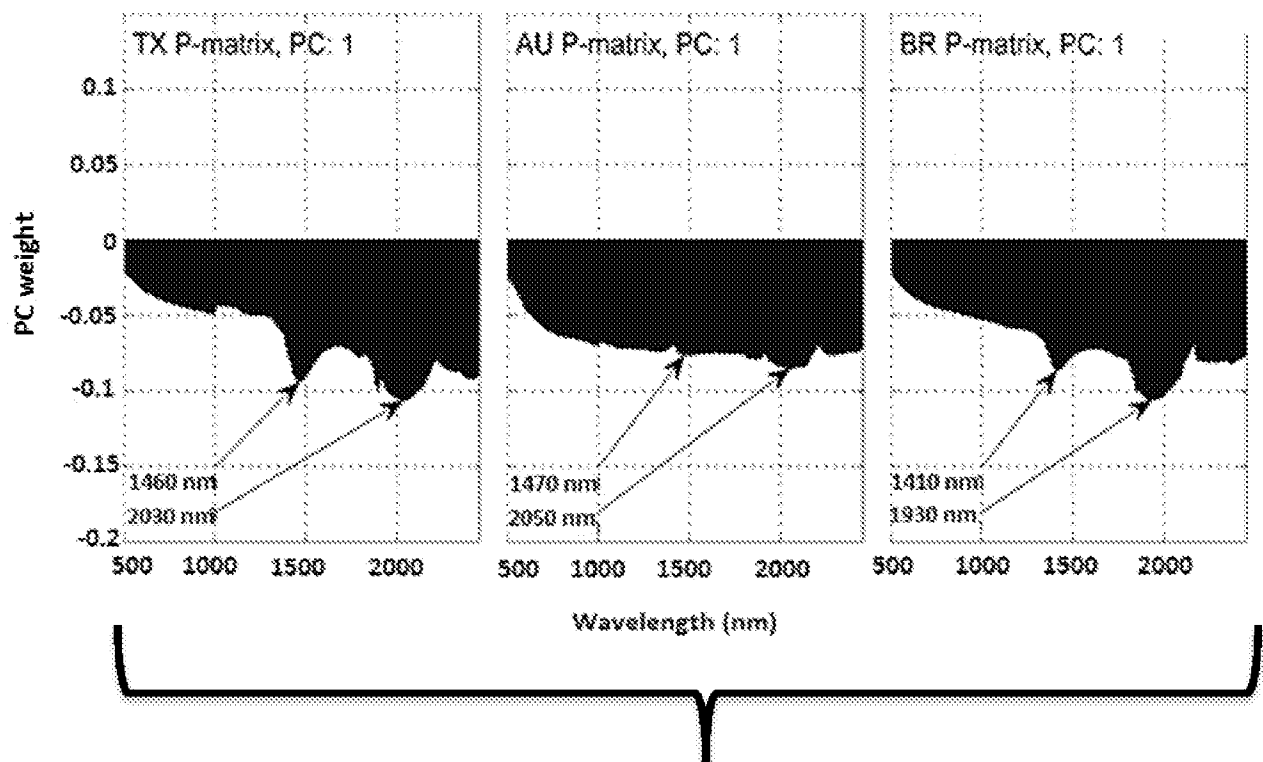


FIG. 8

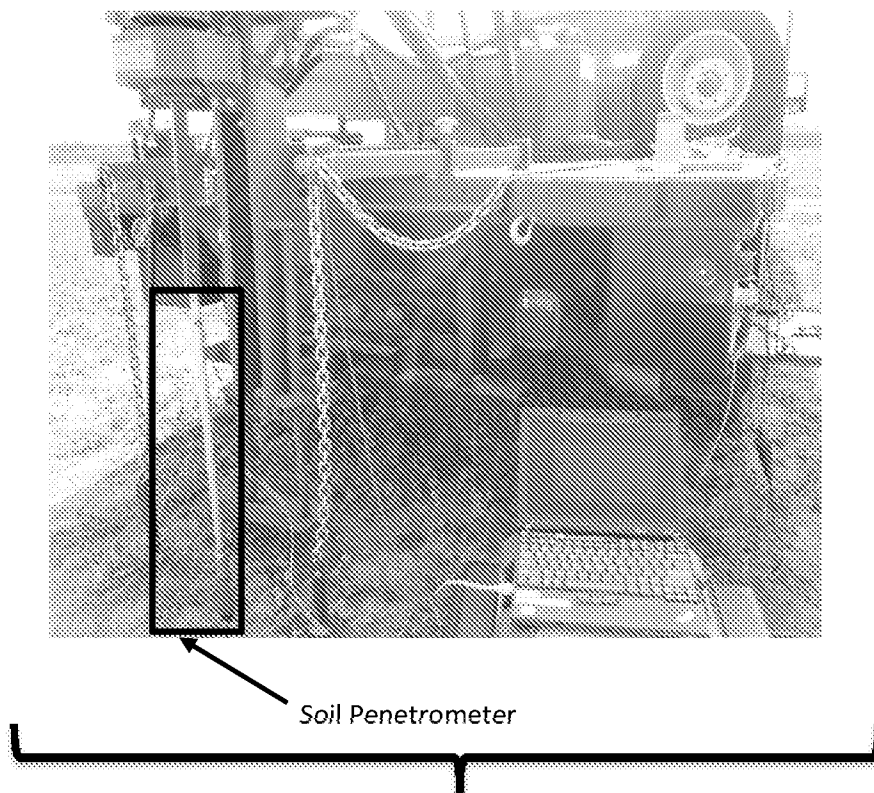
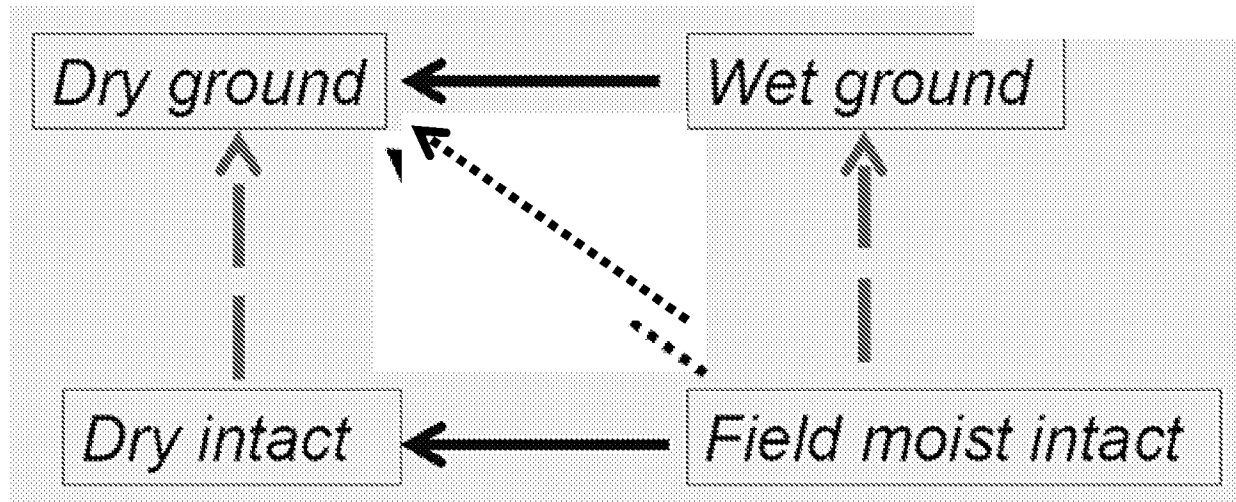


FIG. 9



$$X = XP + XQ + R$$

P = projection matrix of the useful part of the spectra $X^* = XP$

Q = projection matrix of the un-useful part of the spectra (influences by moisture and soil heterogeneity)

R = residual matrix

FIG. 10

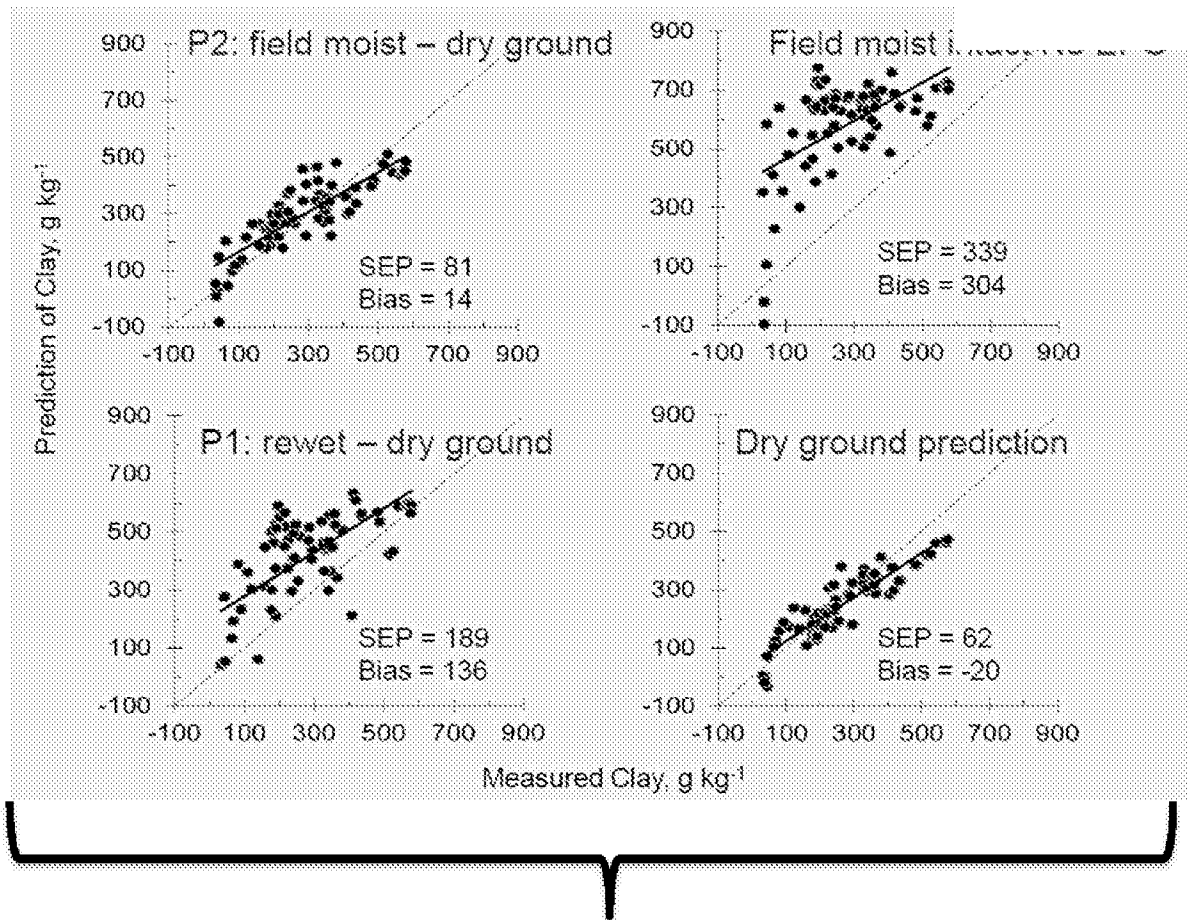


FIG. 11

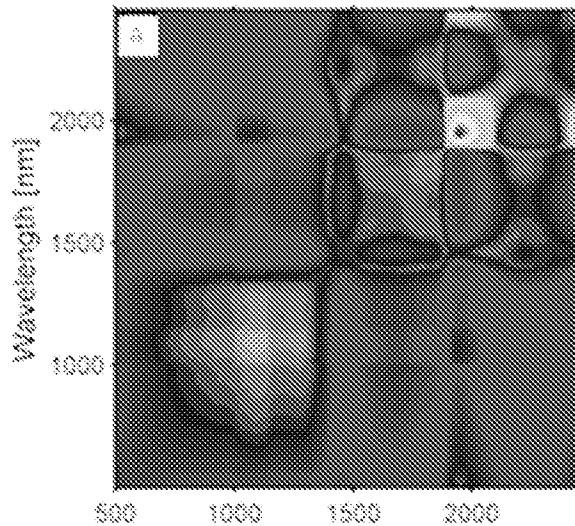


FIG. 12A

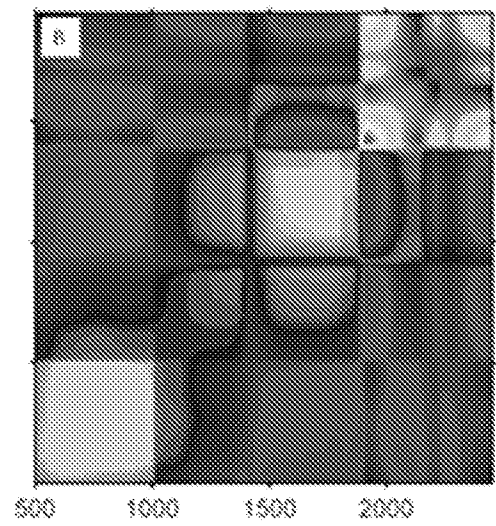


FIG. 12B

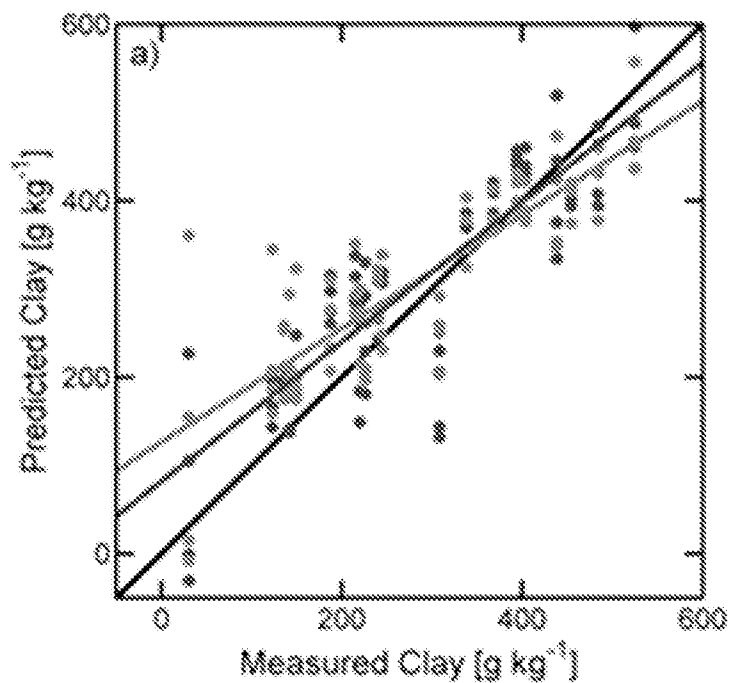


FIG. 13A

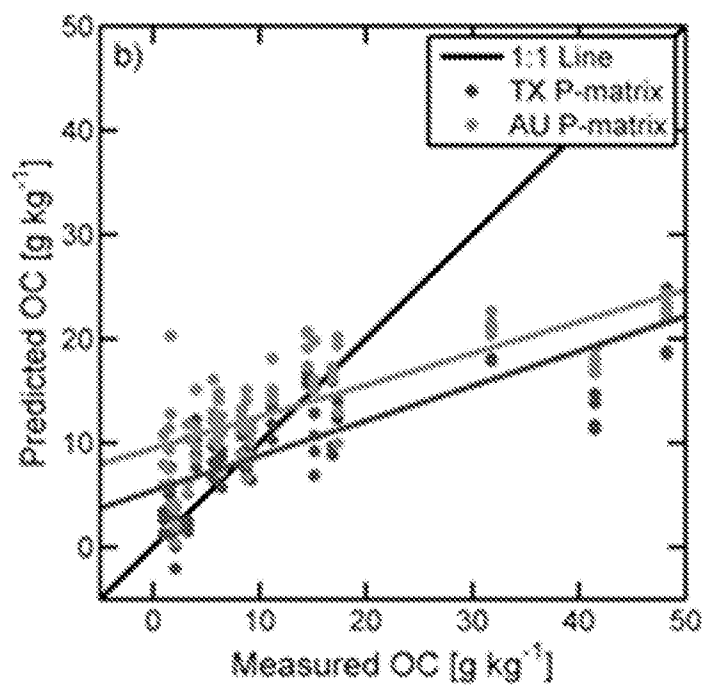


FIG. 13B

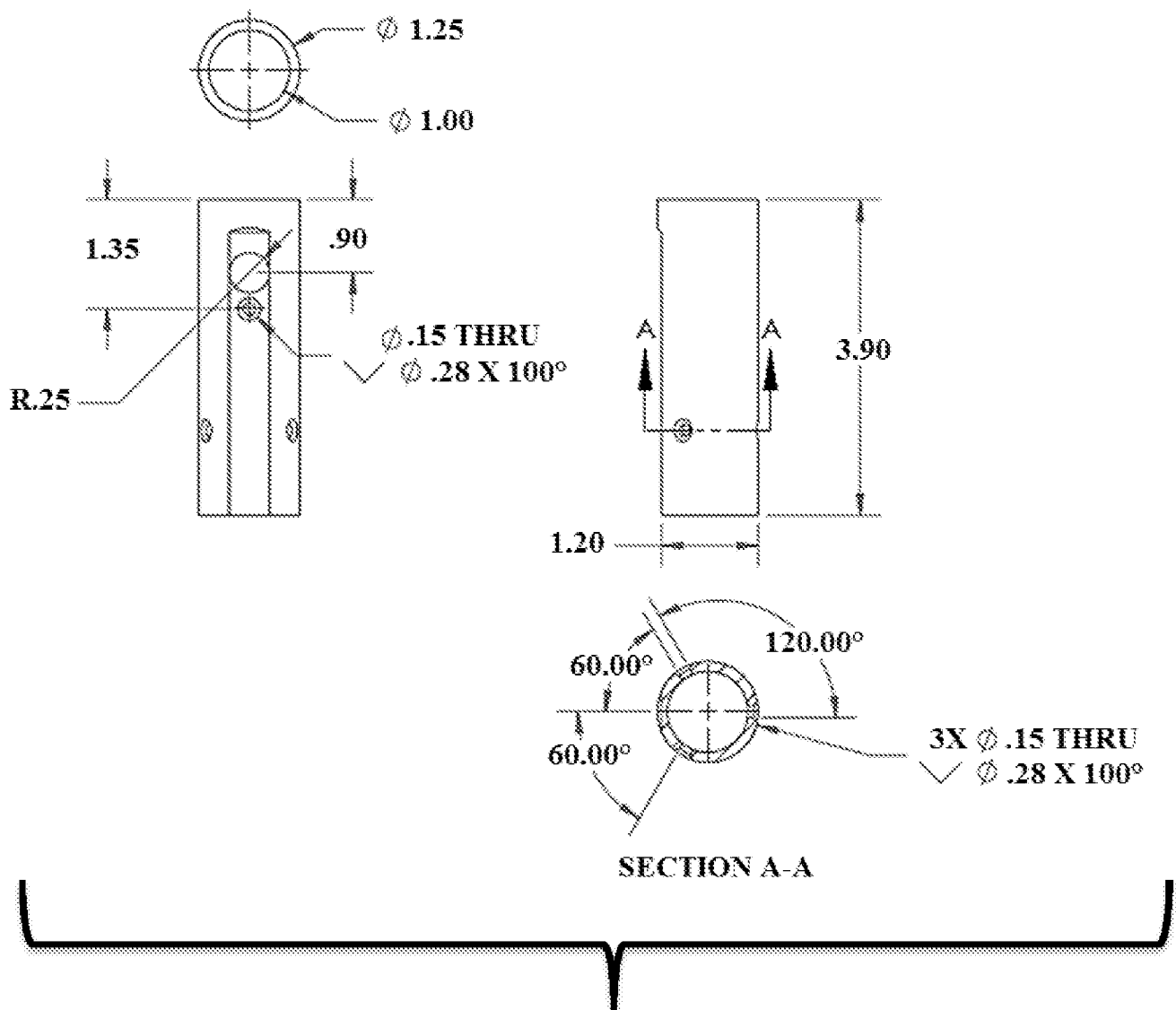


FIG. 14

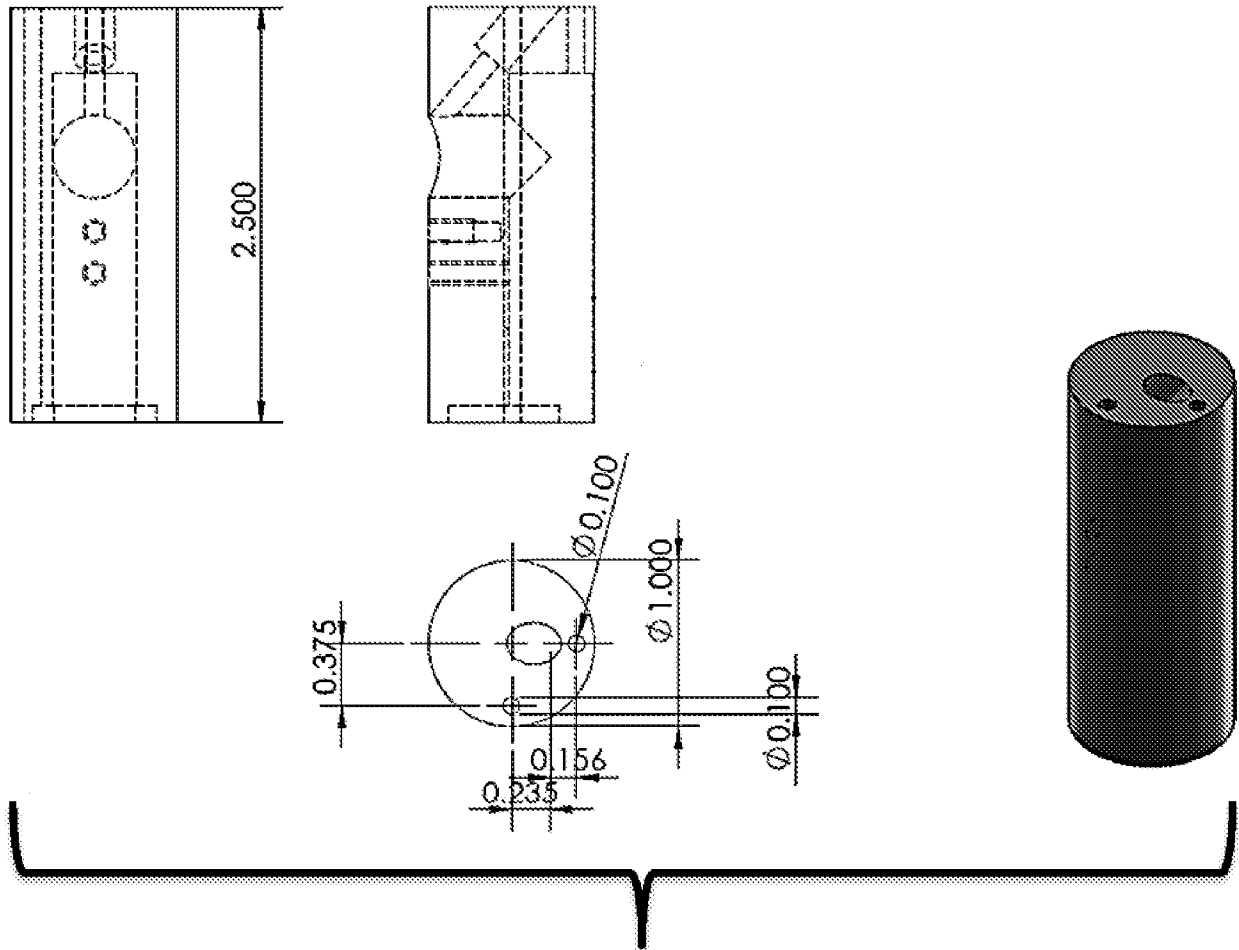


FIG. 15

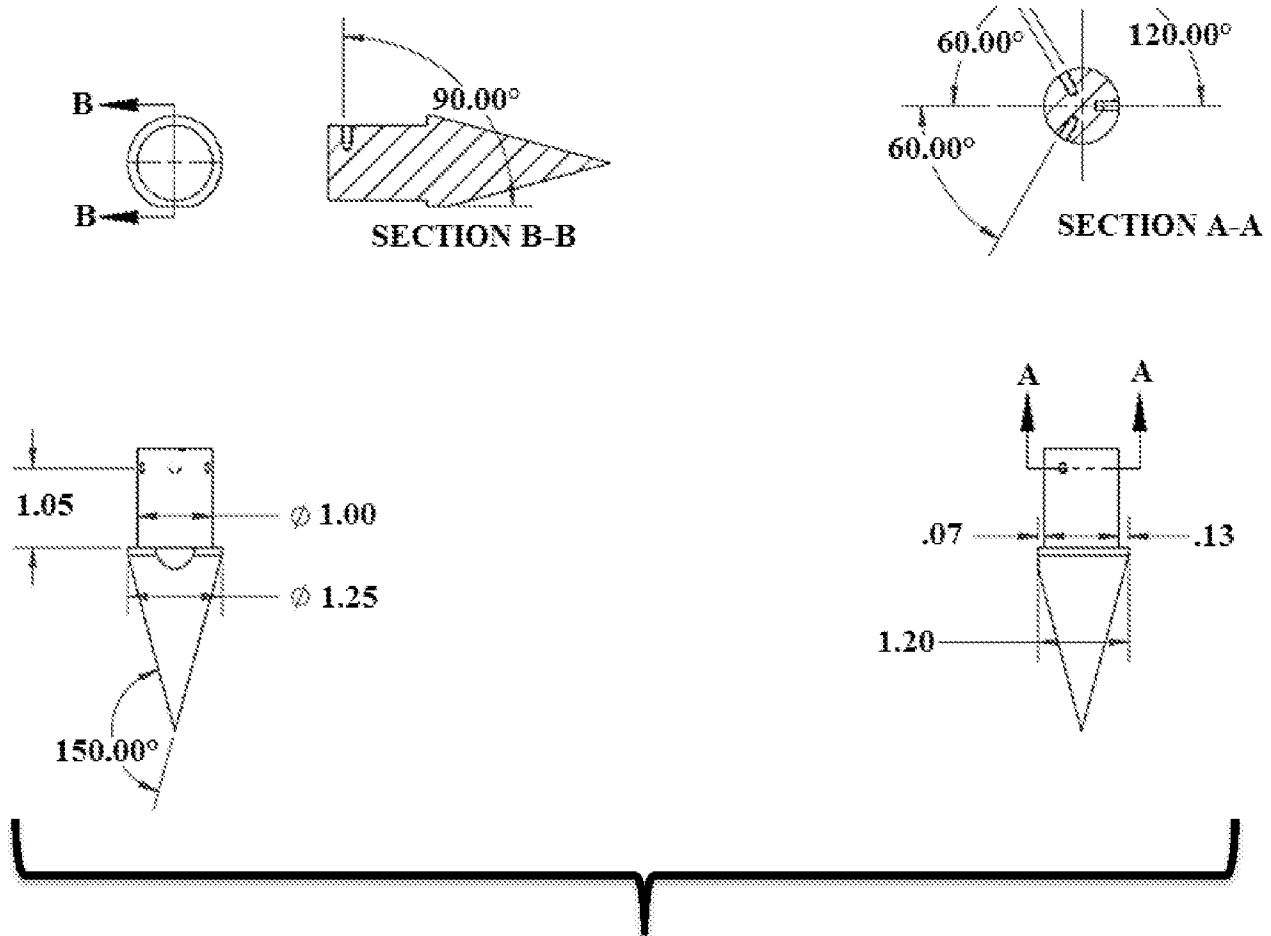


FIG. 16

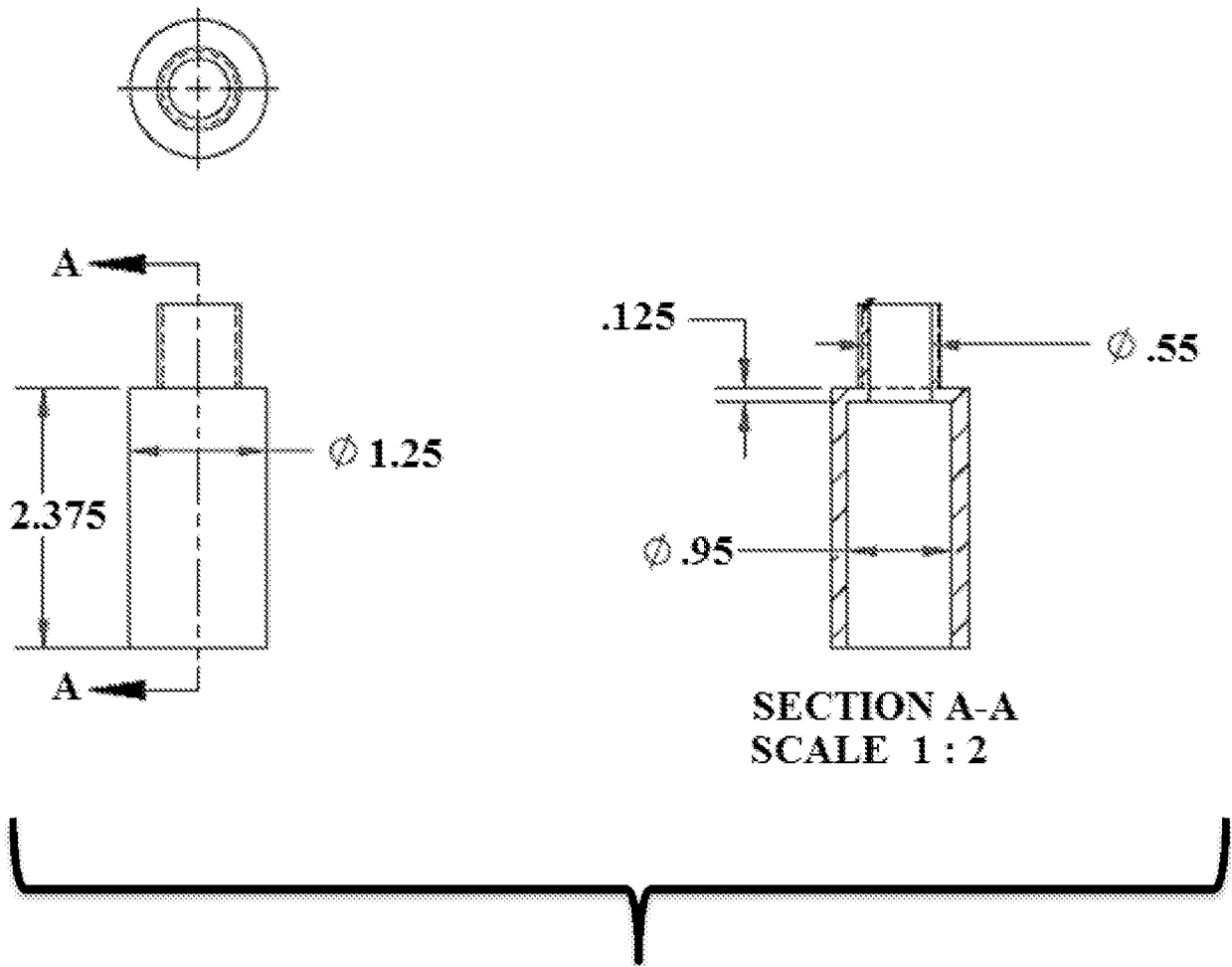


FIG. 17

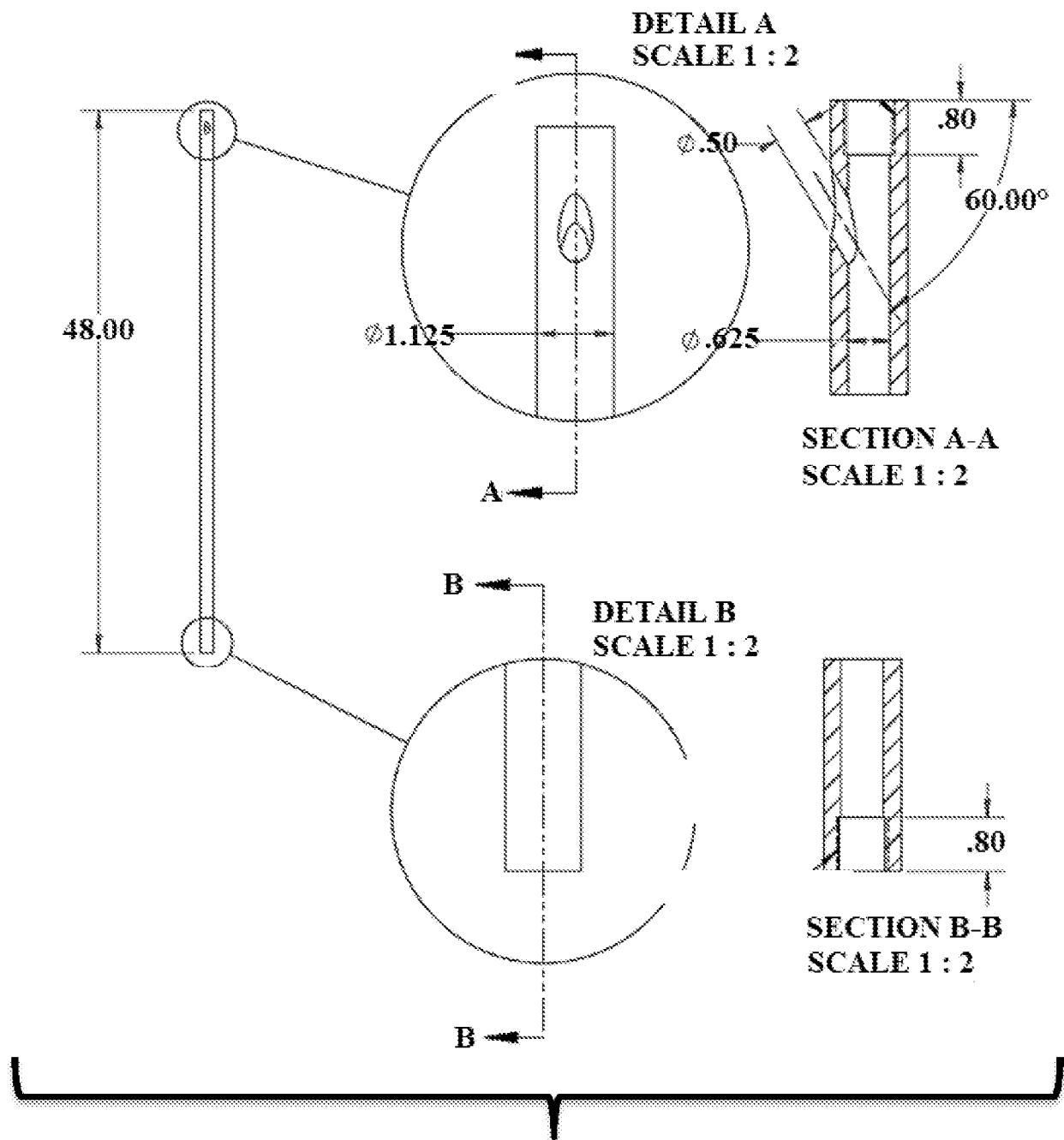


FIG. 18

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/038980

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01N21/85 G01N33/24
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 93/23741 A1 (US ARMY [US]) 25 November 1993 (1993-11-25)	1,4-6,8, 11-15
Y	page 4, lines 24-26 page 15, lines 12-18,20-23 page 13, lines 15,16 page 8, lines 12-15,20,21 page 9, line 19 - page 10, line 8 figure 2	2,3,7,9, 10,16-18
Y	----- US 5 316 950 A (APITZ SABINE E [US] ET AL) 31 May 1994 (1994-05-31) column 9, lines 19-23 column 6, lines 16-19 figure 1 ----- -/-	2,3,9, 10,16-18



Further documents are listed in the continuation of Box C.



See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search

27 September 2017

Date of mailing of the international search report

09/10/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Navas Montero, E

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/038980

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/106451 A1 (CHRISTY COLIN [US] ET AL) 5 May 2011 (2011-05-05)	19,20
Y	paragraphs [0007], [0044], [0045], [0046]; claim 5; figure 7 -----	7
X	US 5 548 115 A (BALLARD JOHN H [US] ET AL) 20 August 1996 (1996-08-20) column 1, lines 56-60 column 3, lines 40-45,47-57,59-61 column 4, lines 31-33,51-54 figures 1,2 -----	1,4-8, 11-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/038980

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9323741	A1	25-11-1993	EP 0604428 A1 06-07-1994 US 5128882 A 07-07-1992 WO 9323741 A1 25-11-1993
US 5316950	A	31-05-1994	NONE
US 2011106451	A1	05-05-2011	NONE
US 5548115	A	20-08-1996	NONE