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(54) **Title**: APPARATUS FOR THE DETECTION AND CLASSIFICATION OF BURIED UNEXPLODED ORDNANCE

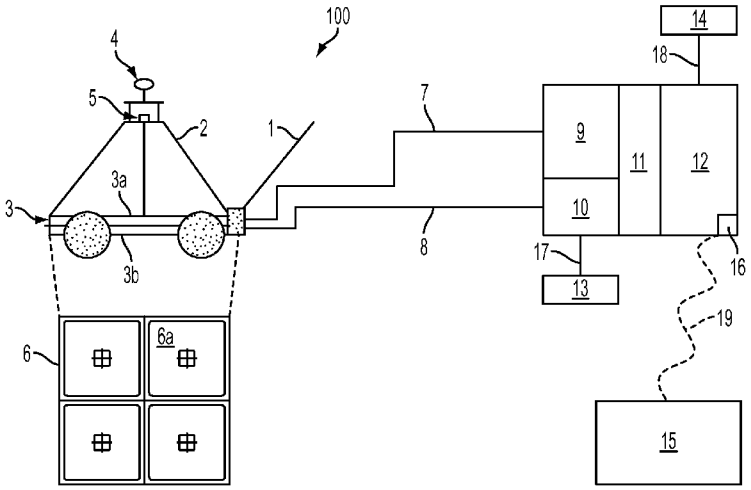


FIG. 1

(57) **Abstract**: A sensor system for detecting buried metal objects such as unexploded ordnance and the collection of data for the classification of the detected objects based on parameters extracted from the collected data includes a wheeled cart, positioned on which is an array of transmitter coils for transmitting a series of excitation signals onto the area of interest and a sensor array of receiver coils and preamplifiers for receiving back the resultant eddy current decays emitted by the buried objects, a computer, and data acquisition electronics for acquiring and storing the received decays as decay data within the computer. The incoming EMI data are digitized and a data fitting process is performed to extract fit location and shape parameters. These data can be transferred to other data analysis systems for comparison to previously recorded signatures to determine whether the received decay data from the area of interest is attributable to buried metal objects or conversely to an object constituting an anomaly.

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SYSTEM FOR THE DETECTION AND CLASSIFICATION OF BURIED UNEXPLODED ORDNANCE

CROSS-REFERENCE TO RELATED APPLICATIONS

This Application claims the benefit of U.S. Provisional Application 61/783,051 filed on March 14, 2013.

TECHNICAL FIELD

The invention is directed to a system for the detection of buried metal objects and the classification of the detected objects on the basis of shape parameters extracted from the modeling of the collected data, and more particularly to a system for distinguishing potentially hazardous buried unexploded ordnance (UXO) from non-hazardous scrap and range debris.

BACKGROUND ART

UXO contamination at former and current Department of Defense (DOD) sites is an extensive problem. Site characterization and remediation activities conducted with the current state-of-the-art technologies at these sites often yield unsatisfactory results and are extremely expensive to implement. This is due in part to the inability of current technology to distinguish between UXO and nonhazardous items.

Present systems that are commercially available include the Geonics EM61-MK2, which although field-tested over many years only provides detection, not classification of UXO. The system also has undesirably large sensor dimensions, and suffers from signal response drift due to its analog electronic design. Another system is the Geometrics MetalMapper, which is used in a vehicle-mounted configuration due to its large size and weight. In survey mode, it can only provide detection because the single transmitter only allows for the collection of a limited data set. In cued, or static mode, UXO classification is possible.

DISCLOSURE OF INVENTION

According to the invention, a sensor system for detecting buried metal objects such as unexploded ordnance and the collection of data for the classification of the detected objects based on parameters extracted from the collected data includes a wheeled cart, positioned on which is an array of transmitter coils for transmitting a series of excitation signals onto the area of interest and a sensor array of receiver coils and preamplifiers for receiving back the resultant eddy current decays emitted by the buried objects, a computer, and data acquisition electronics for acquiring and storing the received decays as decay data within the computer. The incoming EMI data are digitized and a data fitting process is performed to extract fit location and shape parameters. These data can be transferred to other data analysis systems for comparison to previously recorded signatures to determine whether the received decay data from the area of interest are attributable to a metal object or empty soil or space.

Its electromagnetic induction (EMI) sensor capability robustly distinguishes between UXO and nonhazardous items.

The TEMTADS (the "Time-domain Electro-Magnetic MTADS- the "MTADS" acronym stands for Multi-sensor Towed Array Detection System") MP 2x2 Cart (MP System) provides robust UXO/Clutter classification performance in a form factor suitable for use in rugged terrain and other environments where mobility is limited. The system operates one of two modes: In a dynamic data collection mode, a wide area is interrogated to detect metallic objects and potentially classify some fraction of them from the resulting data; and in a cued, or static, data collection mode to support making UXO/Clutter decisions.

Based on the success of the MP System in cued mode, we have explored operating the system in a dynamic, or survey mode for anomaly detection. Anomaly detection performance was found to be comparable to that of the state-of-the-art in terms of Signal-to-Noise Ratio (SNR) and demonstrated improved spatial resolution in the resultant data. Preliminary classification results indicate that at least half of the detected anomalies could be successfully classified from the dynamic data alone, potentially reducing the number anomalies requiring cued data collection.

The invention provides UXO detection and classification capabilities, including in difficult terrain and treed areas. Daily production data collection rates of 1 acre for dynamic survey and 200 anomalies for cued mode are typically achieved, respectively. The system is 80 cm on a side and mounted on a man-portable cart. Relatively small sensors mitigate the problems of data processing / analysis when more than one target appearing under the system at one time.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic diagram of a system for the detection and classification of buried unexploded ordnance according to the invention;

FIG. 2 is an individual TEMTADS/3D EMI sensor according to the invention;

FIG. 3 is an individual TEMTADS/3D EMI sensor with 3 axis receiver under construction according to the invention;

FIG. 4 is a schematic diagram of the EMI sensor array according to the invention showing the relative positions of the four tri-axial EMI sensors;

FIG. 5 is a picture showing the field-deployed TEMTADS Man-Portable 2x2 Cart according to the invention; and

FIG. 6 is a picture showing the field-deployed TEMTADS MP 2x2 Cart with an onboard GPS Antenna Tripod according to the invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to **Figure 1**, system **100** includes a wheeled cart **1** (with a handle for pushing by an operator) mounted on which is a GPS (global positioning system) / IMU (inertial measurement unit) tripod **2** and a sensor bed **3** comprising an upper sensor shell **3a** and a lower shell **3b**. Positioned on tripod **2** are a GPS antenna and receiver for providing the location of the cart **4** (e.g. latitude, longitude, and elevation) and an IMU **5** for providing the orientation of the cart (e.g. Pitch, Roll, and Yaw). A sensor array **6** is sandwiched in between the two parts of the sensor bed **3** and includes TEMTADS/3D sensor **6a**. A receiver cable **7** is attached at a first end to each receiver part of sensor **6a** of sensor array **6** and at a second end to a receiver electronics **9**. A transmitter

cable **8** is attached at a first end to each transmitter portion of sensor **6a** of sensor array **6** and at a second end to a transmitter electronics **10**. Data acquisition electronics **11** acquires the received data and inputs the data to a computer **12**. Power for the transmitter electronics **10** is provided by a transmitter battery **13** and the computer **12** has its own power source in computer battery **14**.

System **100** further includes a control tablet computer **15**, a wireless communications hub **16**, a transmitter battery cable **17**, a computer battery cable **18**, and a wireless communications link **19**.

The Time-Domain Electromagnetic Induction (TEM) TEMTADS/3D EMI sensor **6a** is composed of a 35-cm square transmitter coil **20** with a three-axis receiver cube **21** placed in the center of the transmitter coil. These receiver cubes are similar in design to those used in the second-generation AOL developed by G&G Sciences for the U.S. Navy and in the Geometrics MetalMapper (ESTCP MR-200603) system with dimensions of 8 cm rather than 10 cm. The U.S. Army Cold Regions Research and Engineering Laboratory's (CRREL) MPV2 system (ESTCP MR-201005) uses an array of five identical receiver cubes and a circular transmitter coil. The 8-cm tall transmitter coil is wound on a foam core in a solenoid configuration. The receiver cube for the TEMTADS/3D sensor is based on the receiver cube design used in G&G Sciences TEM sensor systems and in the Geometrics MetalMapper system, which are typically 10cm on a side. The dimensions of the TEMTADS/3D receiver cube are 8cm to match the height of the transmitter coil to simplify packaging. **Figure 2** illustrates in more detail a sensor **6a** comprising upper and lower cover plates **22** and **23** respectively, transmitter coil **24** signal preamplifier **25** receiver coils **26** and foam core **27**. A TEMTADS/3D coil under construction is shown in **Figure 3**.

Decay data are collected with a 500 kHz sample rate until 25ms after turn off of the excitation pulse. A raw decay consists of 12,500 points; too many to be used practically. These raw decay measurements are grouped into a number of logarithmically-spaced "gates" with center times ranging from 25 μs to 24.375 ms and the binned values are saved to disk, that is, to computer and/or processor memory as is further discussed below. In cued mode, the decay measurements are grouped into 122 logarithmically-spaced "gates". In dynamic mode, the decay measurements are grouped into 19 gates with center times out to 2.78 ms.

TEMTADS MP 2x2 Cart

The MP System is a man-portable system comprised of four of the TEMTADS/3D EMI sensors arranged in a 2x2 array as shown schematically in **Figure 4**. The MP System, shown in **Figure 5** at Aberdeen Proving Ground, MD, is fabricated from polyvinyl chloride (PVC) plastic and G-10 fiberglass. The center-to-center distance is 40 cm yielding an 80 cm x 80 cm array. The array is deployed on a set of wheels resulting in a sensor-to-ground offset of approximately 20 cm. The MP System can be operated in two modes; dynamic or survey mode and cued mode. A GPS antenna and an IMU are mounted above the TEM array as shown in **Figure 6**.

Application of this technology is straightforward. A dynamic survey of the system is used to generate a list of anomaly locations. The data collected in the dynamic survey will be of sufficient quality to classify some fraction of the anomalies based on the extracted fit shape parameters and comparison to previously recorded signatures. Flags are manually placed over each remaining anomaly location in advance using cm-level GPS or equivalent. In cued mode, the system is positioned over each target in turn. The transmitters for each array sensor are then fired in sequence, and decay data are collected from all receive coils for each excitation. These data are then stored electronically on the data acquisition computer. A few seconds of platform position and orientation data are collected at the beginning of the EMI data collection. The inverted position determined for each anomaly is initially relative to the array center. The recorded position and orientation data are used to translate the local position into absolute position and orientation. Prior to moving to the next anomaly, the operator evaluates several pieces of information for quality control purposes. The transmit current for each transmitter is compared to established thresholds. A display of the monostatic signal decays for each sensor is reviewed. Additionally, the data can be modeled in the field to determine that the system was accurately placed over the anomaly.

While specific embodiments of the present invention have been shown and described, it should be understood that other modifications, substitutions and alternatives are apparent to one of ordinary skill in the art. Such modifications, substitutions and alternatives can be made without departing from the spirit and scope of the invention, which should be determined from the appended claims. It is further noted that the processing and/or storage of data, e.g. received decay data associated with buried unexploded ordnance or other objects, can be accomplished by executing one

or more sequences of one or more computer-readable instructions read into a memory of one or more computers from volatile or non-volatile computer-readable media capable of storing and/or transferring computer programs or computer-readable instructions for execution by one or more computers. Volatile computer readable media that can be used can include a compact disk, hard disk, floppy disk, tape, magneto-optical disk, PROM (EPROM, EEPROM, flash EPROM), DRAM, SRAM, SDRAM, or any other magnetic medium; punch card, paper tape, or any other physical medium. Non-volatile media can include a memory such as a dynamic memory in a computer. In addition, computer readable media that can be used to store and/or transmit instructions for carrying out methods described herein can include non-physical media such as an electromagnetic carrier wave, acoustic wave, or light wave such as those generated during radio wave and infrared data communications.

CLAIMS

What is claimed as new and desired to be protected by Letters Patent of the United States is:

1. A sensor system designed for the detection of buried metal objects and the collection of data for the classification of the detected objects based on parameters extracted from the collected data, comprising:

a wheeled cart;

an array of transmitter coils positioned onboard the wheeled cart for transmitting a series of excitation signals onto an area of interest and a sensor array of receiver coils and preamplifiers for receiving back the resultant eddy current decays emitted by the buried unexploded ordnance or other metallic objects;

a computer;

data acquisition electronics for acquiring and storing the received decays as decay data within the computer;

and wherein the computer comprises a computer-readable storage medium for recorded data and for software that, when executed by the computer, cause the computer to operate the electromagnetic inductions (EMI) transmitters and receivers, digitize the incoming EMI data, and performing a data fitting process to extract fit location and shape parameters; and wherein these data can be transferred to other data analysis systems for comparison to previously recorded signatures, thereby determining whether the received decay data from

the area of interest is attributable to buried metal objects or conversely to an object constituting an anomaly.

2. The system of claim 1, wherein the sensor array comprises four electromagnetic induction sensors, each containing one or more transmitter, receiver coils, and signal preamplifier.

3. The system of claim 1, further comprising an onboard GPS antenna and receiver for providing the location of the cart.

4. The system of claim 3, further comprising an onboard inertial measurement unit for providing the orientation of the cart.

5. The system of claim 1, further comprising a first battery to power the transmitter and a second battery to power the computer.

6. The system of claim 1, further comprising a wireless communications hub.

7. A sensor system designed for the detection of buried unexploded ordnance and the collection of data for the classification of the detected objects based on parameters extracted from the collected data, comprising:

a wheeled cart;

an array of transmitter coils positioned onboard the wheeled cart for transmitting a series of excitation signals onto an area of interest and a sensor array of receiver coils and preamplifiers for receiving back the resultant eddy current decays emitted by the buried unexploded ordnance or other metallic objects;

a computer;

data acquisition electronics for acquiring and storing the received decays as decay data within the computer;

and wherein the computer comprises a computer-readable storage medium for recorded data and for software that, when executed by the computer, cause the computer to operate the electromagnetic inductions (EMI) transmitters and receivers, digitize the incoming EMI data, and performing a data fitting process to extract fit location and shape parameters; and wherein these data can be transferred to other data analysis systems for comparison to previously recorded signatures, thereby determining whether the received decay data from the area of interest is attributable to buried unexploded ordnance or conversely to an object constituting an anomaly.

8. The system of claim 7, wherein the sensor array comprises four electromagnetic induction sensors, each containing one or more transmitter, receiver coils, and signal preamplifier.

9. The system of claim 7, further comprising an onboard GPS antenna and receiver for providing the location of the cart.

10. The system of claim 9, further comprising an onboard inertial measurement unit for providing the orientation of the cart.

11. The system of claim 7, further comprising a first battery to power the transmitter and a second battery to power the computer.

12. The system of claim 7, further comprising a wireless communications hub.

13. A method for the detection of buried metal objects and the classification of the detected objects on the basis of parameters extracted from the collected data, comprising:

providing a wheeled cart onboard of which is an electromagnetic induction sensor array;

providing a computer, having a computer-readable medium, and data acquisition electronics;

wheeling the cart with the onboard sensor array through an area of interest while transmitting an excitation signal from the sensor array onto the area of interest;

receiving and acquiring decay data at the sensor array;

inputting the decay data to the computer; and

classifying anomalies in the area of interest based on an extracted fit shape parameters by comparison with previously recorded signatures, thereby indicating whether the received decay data are attributable to buried metal objects or conversely to an object constituting an anomaly.

14. The method of claim 13, where the buried metal objects are buried unexploded ordnance.

15. The method of claim 13, further comprising mapping GPS coordinates of interest in the area of interest.

16. The method of claim 13, further comprising utilizing an onboard inertial guidance unit when mapping the GPS coordinates.

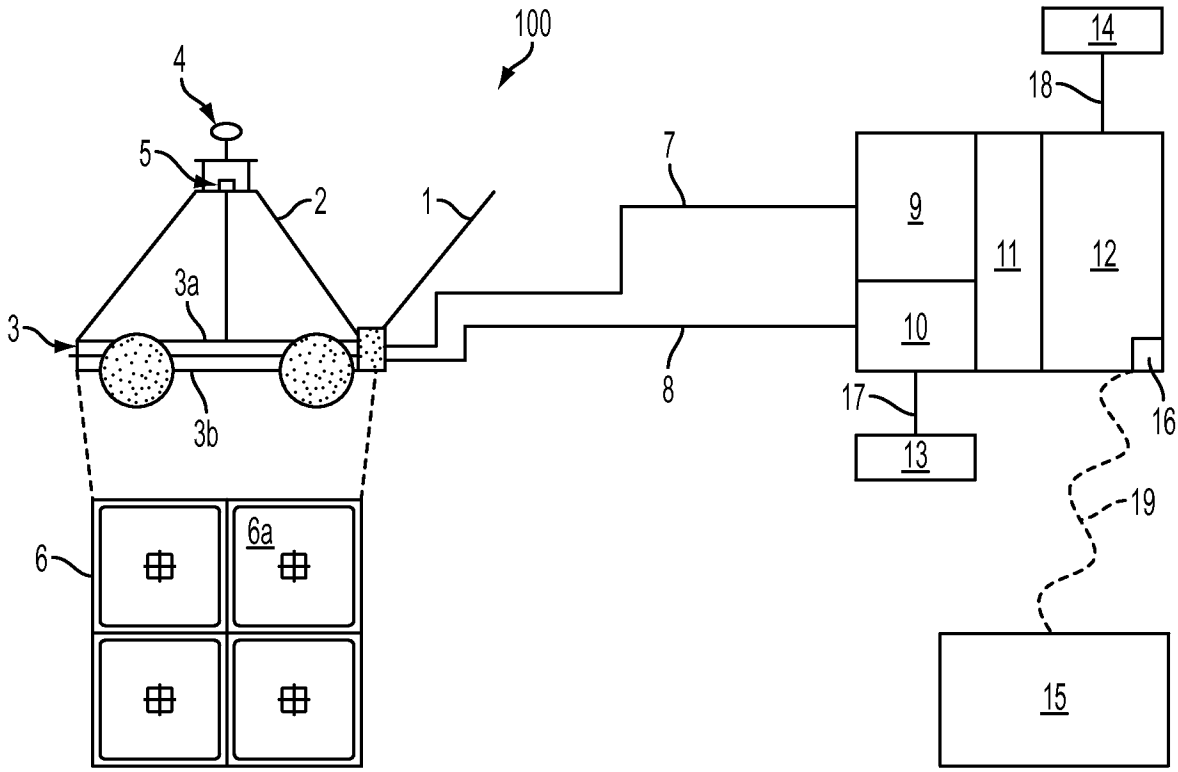


FIG. 1

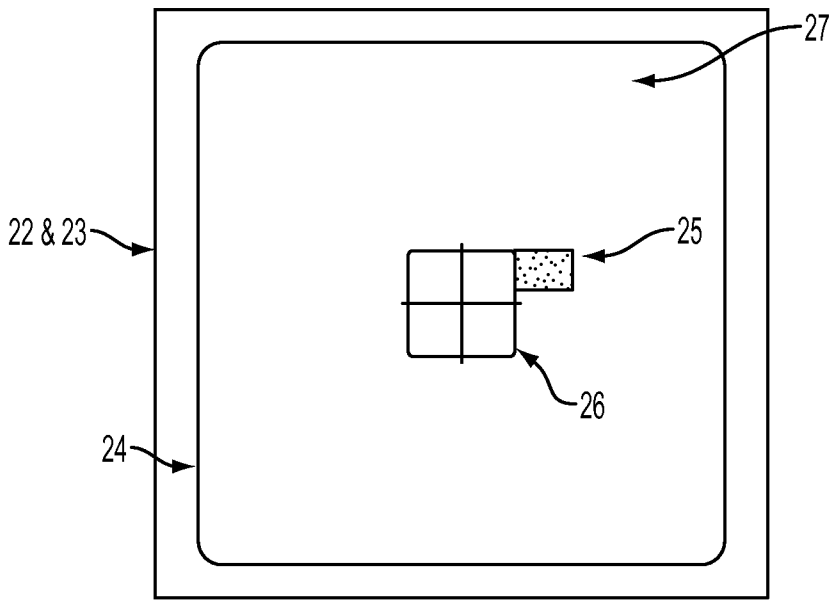


FIG. 2

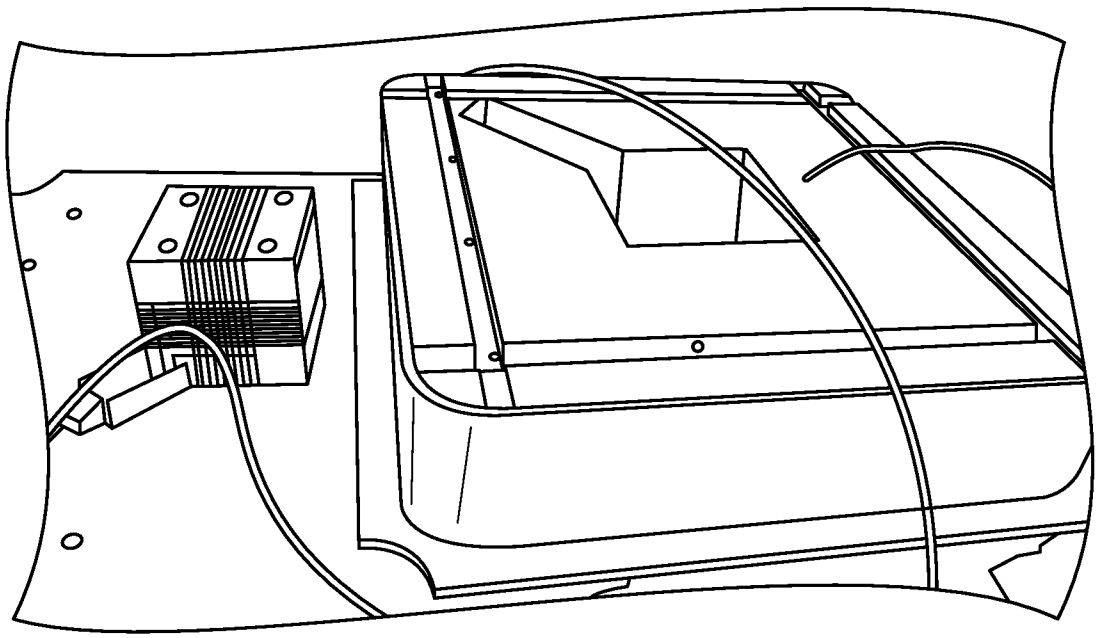


FIG. 3

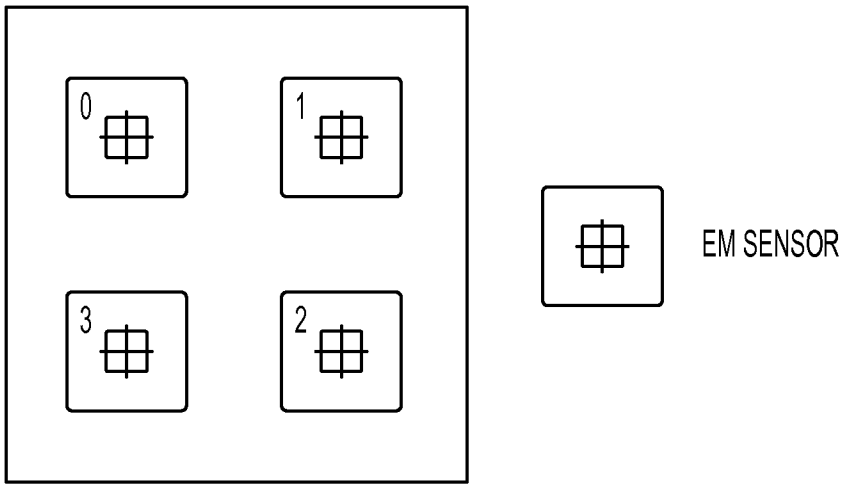


FIG. 4

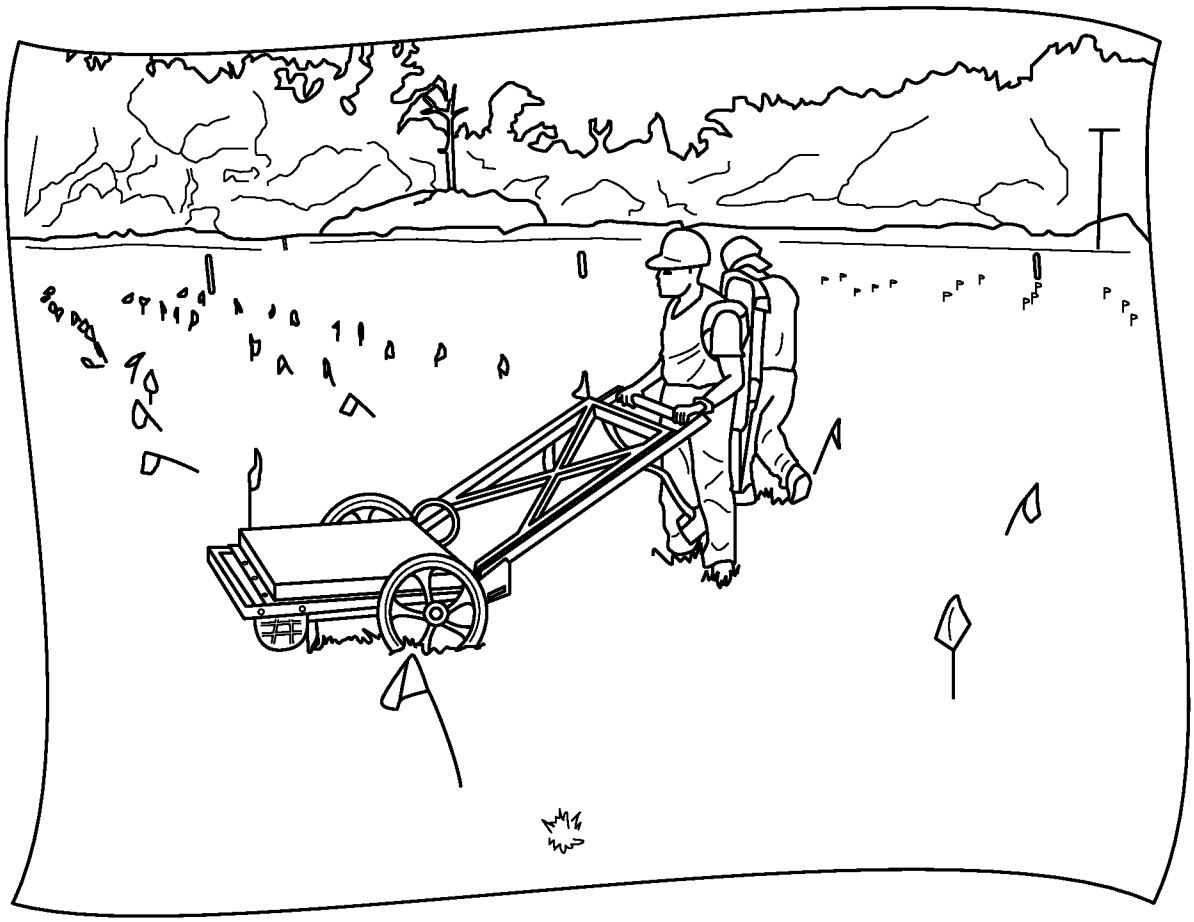


FIG. 5

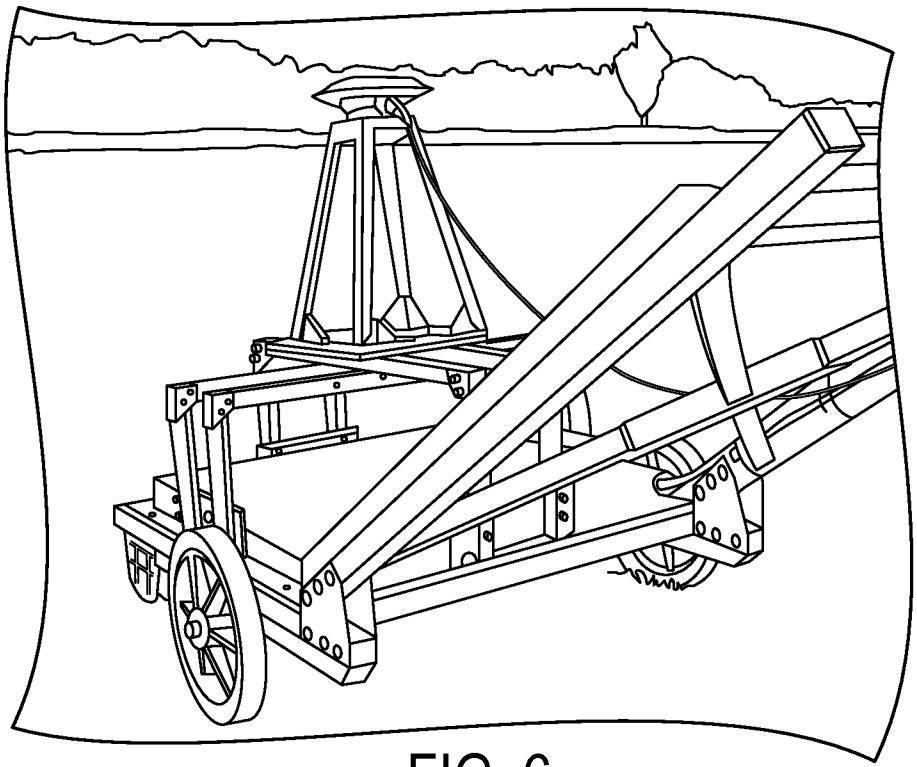


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/022074

A. CLASSIFICATION OF SUBJECT MATTER

G01V 3/165(2006.01)i, G01V 3/08(2006.01)i

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)
G01V 3/165; G01V 3/11; G01V 3/10; G01V 3/08; G01V 3/38; G01R 27/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords:decay, sensor, electromagnetic, coil, transmitter, receiver, preamplifier, buried, ordnance

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004-0000919 A1 (GUPTA et al.) 01 January 2004 See paragraphs [0044]-[0046], claims 1,4,21, and figure 1.	1-16
A	US 6600320 B2 (GUO et al.) 29 July 2003 See column 11, lines 36-54 and figure 11(a).	1-16
A	US 5471143 A (DOANY, ZIYAD H.) 28 November 1995 See claim 16 and figure 2.	1-16
A	US 2003-0052684 A1 (NELSON et al.) 20 March 2003 See paragraphs [0045]-[0057], claims 1,5,12,13, and figure 2.	1-16
A	US 6326791 B1 (BOSNAR, MIRO) 04 December 2001 See claims 1,6 and figure 4.	1-16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"P" document published prior to the international filing date but later than the priority date claimed
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"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
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 June 2014 (18.06.2014)	**19 June 2014 (19.06.2014)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2014/022074

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