

APPARATUS, SYSTEM AND METHOD FOR CLASSIFICATION OF SOIL AND SOIL TYPES

FIELD

- 5 [0001] The present invention relates to an apparatus, system and method for the classification of soil and soil types.

BACKGROUND

- 10 [0002] The following discussion of the background to the invention is intended to facilitate an understanding of the present invention only. It should be appreciated that the discussion is not an acknowledgement or admission that any of the material referred to was published, known or part of the common general knowledge of the person skilled in the art in any jurisdiction as at the priority date of the invention.

- 15 [0003] Soil is an essential resource used in the construction industry. Different types of soil are utilized for different purposes, such as land reclamation and building construction.

- 20 [0004] Soil can typically be excavated from construction sites for a variety of purposes, such as land reclamation. For example, for land reclamation in Singapore, the excavated soil can then be collected at one or more staging grounds and subsequently transported to a land reclamation site, where the excavated soil is used as an infill material. Depending on various properties of the soil, the excavated soil can be classified at least into two soil types – “Good Earth” or “Soft Clay”. Good Earth may be regarded as soils that contain at least 65% by weight of coarse particles (gravel and sand) of size more than 63 micro-meters (μm) and have a moisture content, defined as the proportion of weight of water to the weight of dry soil, of less than 40%. Soft Clay may be regarded as soils that contain at least 35% by weight of fine particles of less than 63 μm; or have more than 40% moisture content, or both. Good Earth typically has good compaction characteristics, whereas Soft Clay typically has poor compaction characteristics. It
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is therefore important to differentiate the Good Earth and Soft Clay before it is transported to the land reclamation site for different uses.

[0005] As shown in Figure 1, current methods of classifying excavated soil involves the collection of physical soil samples and sending them for laboratory testing to determine the soil type, before construction activities takes place to excavate the soil to be sent to the collection points, i.e. staging grounds. This process typically takes a long time (weeks) and may fail to consider the possibility of spatial variations in geology, i.e. excavations of soil at a particular construction site can yield different types of soil depending on location and depth. Therefore, the physical soil samples collected for laboratory testing may not be representative of the construction sites where the soil samples are obtained.

[0006] In addition, when the excavated soil is received at the collection points, i.e. staging grounds, one or more operators carry out a final check on the type of excavated soil by visual inspection. This leaves room for error in classifying soil as a human being's perception can be highly subjective.

[0007] In view of the above, there exists a need to improve the process of soil classification. It is an object to meet the need at least in part.

SUMMARY

[0008] The applicant aims to meet the need by providing an apparatus, system and method for the identification and classification of a soil mass into at least two soil types. The apparatus, system and method seek to provide a technical solution that is relatively faster and minimize errors arising from the subjectivity of human perception.

[0009] Aspects of the apparatus, system and method provide a quick and non-destructive method to determine a soil's classification drawing reference from a standardized system, such as the Unified Soil Classification System.

[0010] The technical solution provides for a device to acquire a digital image(s) of a soil mass, and another device component to obtain soil parameter measurements, such as electrical resistivity measurements of the soil. The data

obtained from the devices are then processed by a processor installed with a probabilistic decision-making algorithm or a user-defined decision-making algorithm. The probabilistic decision-making algorithm or user-defined decision-making algorithm may include a machine-learning algorithm for classifying the excavated soil. Advantageously, the entire process from data collection to decision-making can be automated and considerably shortened compared to prior art. In particular, the technical solution can effectively omit the need for some prior art processes that are time-consuming, labour-intensive and subjective, such as soil sampling and obtaining borehole data at the construction site, conducting soil testing (index properties tests) in the laboratory and manually deciding the appropriate soil classification by visual inspection when the excavated soil is collected at the staging grounds.

[0011] According to an aspect there is an apparatus for identification and classification of soil types. The apparatus includes an image acquisition module and at least one light source mounted on a panel; a soil parameter measurement device to measure a parameter associated with a soil type, and a drive operable to move the image acquisition module and/or soil parameter measurement device along at least one axis.

[0012] In some embodiments, the image acquisition module includes a camera and a distance sensor.

[0013] In some embodiments, the at least one light source is a white light source with colour temperature between 3000 K and 4000 K. The white light source may comprise a plurality of LED flood lights. In some embodiments, there comprises 124 LED flood lights.

[0014] In some embodiments, the distance sensor is a laser distance sensor. The distance sensor is operable to detect distances of between 0.5 metres (m) and 1.2 m.

[0015] In some embodiments, the plurality of probes includes a first set of two probes for sending an electrical current into a soil mass, and a second set of two probes for detecting an electrical potential or voltage across the two probes.

[0016] In some embodiments, the soil parameter measurement device includes a moisture probe.

[0017] According to another aspect there is a system for identification and classification of soil types. The system includes an image acquisition module for obtaining at least one image of a soil mass; a soil parameter measurement module for measuring a parameter of the soil mass; a processor operable to receive the at least one image and the soil parameter measurement(s), wherein the processor includes a classification module operable to classify the soil mass to one of at least two soil types.

[0018] In some embodiments, the classification module includes a first module to classify the soil mass based on a machine learning algorithm, and a second module to classify the soil mass based on the soil parameter measurement. In some embodiments, the machine learning algorithm is based on an artificial neural network.

[0019] In some embodiments, the at least two soil types include Good Earth and Soft Clay.

[0020] In some embodiments, classification of the soil mass based on the soil parameter measurement is activated if the machine learning algorithm is unable to classify the soil mass.

[0021] In some embodiments, the soil parameter measurement module includes a moisture probe.

[0022] According to another aspect there is a method for identification and classification of soil types. The method includes the steps of: - (a.) moving an image acquisition module and a soil parameter measurement device towards a soil mass; (b.) acquiring an image of the soil mass; (c.) measuring the soil parameter of the soil mass; (d.) sending the image and parameter measurement to a processor; (e.) classifying by the processor the soil mass; wherein the classification step includes classifying the soil mass to one of at least two soil types.

[0023] According to another aspect there is a processor having an input module

to receive a first set of soil images and a second set of soil parameter measurements wherein the processor includes a classification module operable to classify the soil mass to one of at least two soil types.

[0024] According to another aspect there is a non-transitory computer readable medium for storage of a computer readable codes capable of executing the method

[0025] Other aspects and features will become apparent to those of ordinary skill in the art upon review of the following description of specific embodiments in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] In the figures, which illustrate, by way of example only, embodiments of the present invention,

[0027] **Figure 1:** shows a prior art method/process for classifying excavated soil;

[0028] **Figure 2:** shows an embodiment of the present disclosure;

[0029] **Figure 3:** shows an apparatus for identification and classification of soil types according to some embodiments;

[0030] **Figure 4a:** shows an image acquisition module according to some embodiments;

[0031] **Figure 4b:** shows a soil measurement device according to some embodiments;

[0032] **Figure 5:** shows a user-interface, in the form of a Graphical User Interface (GUI) to control the apparatus for identification and classification of soil types according to some embodiments;

[0033] **Figure 6:** shows a processor for receiving data from an image acquisition module and a soil parameter measurement device for identification and classification of soil types according to some embodiments;

[0034] **Figure 7:** shows an image processing method according to some embodiments;

[0035] **Figure 8:** illustrates a Grey Level Co-Occurrence Matrix (GLCM) as part of an image processing method according to some embodiments;

5 [0036] **Figure 9:** lists the equations for five GLCM textural features according to some embodiments;

[0037] **Figure 10:** is a flow chart showing a method for classifying a soil mass into a particular soil type according to some embodiments; and

10 [0038] **Figure 11:** is an example of a user interface displaying the overall soil type prediction and a table showing possible predicted soil types.

DETAILED DESCRIPTION

15 [0039] Throughout this document, unless otherwise indicated to the contrary, the terms “comprising”, “consisting of”, “having” and the like, are to be construed as non-exhaustive, or in other words, as meaning “including, but not limited to”.

[0040] Furthermore, throughout the specification, unless the context requires otherwise, the word “include” or variations such as “includes” or “including” will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

20 [0041] Throughout the description, the term ‘soil’ refers to one or more layers of earth where construction activities can take place. The one or more layers of soil can include a mixture of organic remains, clay, silt, sand and rock particles. In the context of the disclosure, the term ‘soil’ include at least soil types such as Good Earth and Soft Clay. The term ‘soil mass’ refers to soil excavated from a site and
25 transported to a location for classification. It is appreciable that the soil may be suitable for land reclamation.

[0042] Throughout the description, the term ‘Good Earth’ refers to a soil type that is compactable to form a stable fill. It comprises generally of soil that contain at

least 65% by weight of coarse particles (gravel and sand) of size more than 63 micro-meters (μm) and have a moisture content of less than 40%. The term 'Soft Clay' refers to a soil type that is fine-grained, containing at least 35% by weight of fine particles of less than 63 μm ; or soil type having more than 40% moisture content, or both. Soft Clay is typically weak in shear strength, more compressible, and has low permeability. Soft Clay may include cohesive soils and marine clay.

[0043] Throughout the description, it is to be appreciated that the term 'processor' and its plural form include microcontrollers, microprocessors, programmable integrated circuit chips such as application specific integrated circuit chip (ASIC), computer servers, electronic devices, and/or combination thereof capable of processing one or more input electronic signals to produce one or more output electronic signals. The processor includes one or more input modules and one or more output modules for processing of electronic signals.

[0044] Throughout the description, it is to be appreciated that the term 'server' and its plural form can include local, distributed servers, and combinations of both local and distributed servers.

[0045] Throughout the description, it is to be appreciated that the term 'channel' or 'channels' include wired or wireless electronic communication channels. The wireless electronic communication channels may include, but is not limited to, Wi-Fi, Bluetooth, Bluetooth LE, GPRS (General Packet Radio Service), Enhanced Data GSM Evolution (EDGE) etc.

[0046] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as is commonly understood by a skilled person to which the subject matter herein belongs.

[0047] According to an aspect there is an apparatus for identification and classification of soil types. The apparatus includes an image acquisition module and at least one light source. The at least one light source may be mounted on a panel. The apparatus includes a soil parameter measurement device to measure a parameter associated with a soil type, and a drive operable to move the image acquisition module and/or soil parameter measurement device along at least one axis.

[0048] Referring to Figure 3, there is an apparatus 10 for identification and classification of a soil mass 30 into two or more soil types. The apparatus 10 is especially suited for deployment at a land reclamation staging ground where soil and other equipment are prepared and/or assembled before deployment. The soil mass 30 may be transported to the land reclamation staging ground via trucks or other vehicles.

[0049] The apparatus 10 comprises an image acquisition module 12 and a soil parameter measurement device 14. The image acquisition module 12 may include an image acquisition device 18, and light source 20 for illumination of one or more truckload full of soil mass 30. The light source 20 may be in the form of a Light Emitting Diode (LED) panel 22 having a plurality of LED lights for illuminating the soil mass 30 before one or more images of the soil mass 30 are captured. In some embodiments, the image acquisition module 12 and the soil parameter measurement device 14 may be mounted on a frame.

[0050] The image acquisition device 18 can be a camera or a video camera. The image acquisition module 12 may further include a distance sensor 24 positioned adjacent the image acquisition device 18 to detect an optimal distance from the soil mass 30 for image acquisition.

[0051] In some embodiments, the at least one light source 20 may be a white light source with colour temperature between 3000 K and 4000 K. The white light source may comprise a plurality of LED flood lights. In some embodiments, there comprises between 80 and 150 flood lights. In some embodiments, there are 124 LED flood lights.

[0052] In some embodiments, the distance sensor is a laser distance sensor 24. The distance sensor 24 is operable to detect distances of between 0.5 metres (m) and 1.2 m from the soil mass 30 to cater for different vehicles transporting the soil mass 30. The distance sensor may include a controller operable to receive and/or send control signals to detect proximity with the ROI of the soil mass 30.

[0053] The image acquisition module 12 can be moved towards a soil mass 30 via a drive, such as a DC motor, for capturing of images of the soil mass 30. As illustrated in Figure 4a, the image acquisition module 12 is configured and arranged

to capture images of a soil surface (of a soil mass) at a consistent illuminance. The desired Region of Interest (ROI) of the soil surface can be pre-determined by a user, and the exact equipment to be included in the setup is to be selected or adjusted accordingly. The image acquisition module 12 may include a drive motor 13 (via an extension mechanism 17) which operates to move the camera 18 towards the soil mass 30. The extension mechanism 17 includes threaded rod 19 and guide rails to facilitate extension of the camera 18 towards the soil mass 30 for acquiring one or more images. The camera 18 can be mounted on a frame 26.

[0054] Each image captured by the image acquisition device 18 preferably have a horizontal and vertical resolution of 96 dots per inch (dpi), and comprises a minimum size of 2592 pixels in width and 2048 pixels in height.

[0055] In some embodiments, the image acquisition device 18 may be an industrial grade camera 18. In some embodiments, the image acquisition module 12 may include a programmable module for pre-settings by one or more users. The programmable module may be based on known programmes such as LabView™ or MatLab™.

[0056] The at least one light source 20 may include a controller module which is arranged in signal communication with a processor (not shown) to receive control signals to switch the light source 20 on/off or adjust the light intensity of the same. In general, the light source 20 is arranged in a manner such as to provide a relatively constant illumination on the region of interest, for example the surface of a soil mass 30.

[0057] In some embodiments, the soil parameter measurement device 14 may be as illustrated in Figure 4b. Figure 4b shows the soil parameter measurement device 14 in the form of a soil electrical resistivity measurement device 40. The soil electrical resistivity measurement device 40 includes a plurality of probes which include first set of two probes 42 for sending an electrical current into a soil, and a second set of two probes for 44 detecting an electrical voltage. It is appreciable that for taking measurements, the first set of probes 42 and second set of probes 44 are inserted into the soil mass 30.

[0058] In some embodiments, the probes are arranged in a Wenner's array

configuration, where four electrodes are arranged in-line and separated by equal intervals. The first set of two probes 42 are the outer two electrodes (labelled as 'A' and 'B') which allows electrical current to pass through (also referred to as source electrodes). The second set of two probes 44 are the inner two electrodes (labelled as 'M' and 'N') which allows electrical potential across the electrodes 'M' and 'N' (also referred to as receiver electrodes) to be measured. An electrical direct current (DC) is supplied to the electrodes 'A' and 'B' when the two electrodes are implanted in the soil mass 30, and the difference of electric potential between two electrodes 'M' and 'N' is measured. In the embodiment illustrated in Figure 4b, the source electrodes may be current electrodes and the receiver electrodes may be voltage electrodes. It is appreciable that other types of arrays may be used in addition or in alternative to calculate/derive the electrical resistivity of soil. For example, a Schlumberger, a dipole-dipole array or combinations of the aforementioned may be used.

[0059] The current I and voltage V may be expressed mathematically with the apparent electrical resistivity ρ_A of the soil mass 30 calculated using the expression below:

$$\rho_A = 2\pi a \frac{V}{I} \quad (1)$$

Where

ρ_A is the apparent electrical resistivity (Ωm)

a is the distance between the electrodes (m)

V is the electrical potential difference (voltage) (V)

I is the current (A)

[0060] It is to be appreciated that the exact equipment to be included in the setup can be selected or adjusted according to the required soil volume, depth and distance from the setup to the soil surface.

[0061] Figure 4b also shows the soil electrical resistivity measurement device 40 in some embodiments. The soil electrical resistivity measurement device 40 includes the following components, an actuator 46, and a multimeter 52 in addition to the first and second set of source electrodes 42 and receiver electrodes 44.

[0062] Actuator 46 is arranged to enable the probes 42, 44 (collectively referred to as 'electrical resistivity probes') to move down from a higher position (which may be a start position), and subsequently push the measurement rods (which may be metallic rods, that which can conduct electricity) into the surface of the soil mass

5 30. Actuator 46 can include a motor drive arrangement to move the probes towards or away from the soil mass 30. There comprises a rail arrangement 48 (also referred to as guard rail) to guide the actuator 46 and electrical resistivity probes 42, 44 along a desired or predetermined direction, e.g. upwards or downwards.

[0063] The electrical resistivity probes may be mounted onto a mounting frame

10 50. The mounting frame 50 can be a solid platform that enable attachment of the soil electrical resistivity measurement device thereon.

[0064] A multimeter 52 may be attached to the probes to measure the electrical resistivity of the soil mass 30 (when inserted therein).

[0065] In some embodiments, the electrodes may be shaped and dimensioned

15 as having 20 millimetres (mm) diameter and 100 mm length. The electrodes may include steel, or stainless-steel rods to prevent or minimize oxidation.

[0066] In some embodiments, the spacing between each electrode and its adjacent electrode is about 200 mm. In general it is appreciable that the closer spacing between each electrode with its adjacent electrode, the smaller the

20 thickness of the soil layer from the surface of the soil mass for which the apparent electrical resistivity is computed. A 200 mm electrode spacing is reasonably adequate to check the apparent electrical resistivity of the interested soil depth.

[0067] The actuator 46 may be shaped, dimensioned and configured as follows. Stroke length of 1 metres (m) to 2 m; A pushing force (insertion into the soil mass)

25 in the range of 1 kilo-newton (kN) to 10 kN; have a movement speed in the range of 1 m/min to 5 m/min.

[0068] In some embodiments, the actuator 46 may be programmed and controlled by a software component, such as being arranged in signal communication with a processor/controller to move the actuator towards or away

30 from the soil mass 30 at a desired speed. In some embodiments, the actuator 46

may include three 'stop' modes, which are configured to stop operation of the actuator under any of the following conditions: (i.) Maximum force (Pre-set by the user); (ii.) Stroke length (Pre-set by the user); (iii.) Emergency stop.

[0069] In some embodiments, multimeter 52 is configured to monitor and measure the current and voltage in the electrodes 42, 44. The measured voltage and current values may be data logged and saved in a designated folder predefined by a user. It is to be appreciated that the duration for measurement and data storage may be kept within 20 seconds.

[0070] In some embodiments, the soil parameter measurement device 14 includes a moisture probe 28. The moisture probe 28 may be arranged to detect the moisture content of the soil mass 30. It is appreciable that moisture content data may be used as an added soil parameter or may be used to derive one or more other parameters for the classification of soil type.

[0071] The image acquisition module 12 and soil parameter measurement device 14 can be operated through a user-interface. The user interface may include a Graphical User Interface (GUI) as shown in Figure 5. In the GUI, an "Activate" button can be programmed to activate the image acquisition module 12 and soil parameter measurement device 14 simultaneously, at the same time, or sequentially.

[0072] Upon activation, the at least one light source 20 is activated or turned on, and the camera 18 is lowered to a distance pre-defined by a user based on feedback from the laser distance sensor 24. At the same time, the electrodes 42, 44 are lowered into the soil mass 30, and a current is transmitted into the soil mass 30. Once the required data are acquired by the camera 18 and the multimeter 52, the camera 18 and the electrodes 42, 44 can be withdrawn to their idle or starting positions automatically.

[0073] It is appreciable that the image acquisition module 12 and the soil parameter measurement device 14 can also be operated manually through the "Manual Control" buttons on the GUI.

[0074] According to another aspect there is a system for identification and

classification of soil types. The system may include a processor or computer server having input and output modules to receive and send data. The processor may be arranged in data or signal communication with the image acquisition module 12 and the soil parameter measurement device 14 to receive images from the image acquisition module 12 and soil parameter data from the soil parameter measurement device 14. It is appreciable that the images may be received directly or indirectly (via one or more interfaces) from the respective image acquisition module 12 and soil parameter measurement device 14. The GUI as shown in Figure 5 may be used to send control signals to the processor which in turn is used to actuate the image acquisition module 12 and/or the soil parameter measurement device 14. The data or signal communication may be achieved via wired or wireless electronic communication channels.

[0075] As shown in Figure 6, the processor 60 may comprise physical or logical modules to perform various functions. In the illustrated embodiment shown in Figure 6, the processor 60 includes a data acquisition module 62, a data analysis module 64, and a decision-making module 66. One or more of the modules may be accessible by a user via a GUI 68 to perform different functions. The GUI 68 may be the same GUI 68 as illustrated in Figure 5 or may be a separate GUI.

[0076] The data acquisition module 62 is operable to obtain image data from the apparatus 10, in particular from the image acquisition module 12 and soil parameter data from the soil parameter measurement device 14. The image data may be in the form of one or more images captured by the image acquisition module 12 in one or more acceptable data formats such as JPEG, BMP and RAW file formats. The soil parameter data may include electrical resistivity, voltage and current data. Once the soil parameter data is obtained, it will be sent to the data analysis module 64 where the data will be analysed for classification by the decision-making module 66. The classification results may be sent to the GUI 68 for display. The GUI 68 may be used to access information from modules 62, 64 and 66 for display to a user.

[0077] In some embodiments, upon a user's activation of the apparatus 10, the laser distance sensor 24 detects the distance of the image acquisition module 12 (e.g. a camera) to the surface of a soil mass 30. Based on feedback from the laser

distance sensor 24, the camera 12 is lowered automatically in preparation to capture one or more images at a predetermined distance above the soil surface. When the camera 18 is in position, the at least one light source 20 is automatically triggered, and a predetermined resolution of the image, such as a 24-bit image of the region of interest, is then acquired.

[0078] In some embodiments, the file of the acquired image may be named automatically and then systematically stored into a designated folder in the processor hard drive in one or more acceptable file formats.

[0079] In some embodiments, upon a user's activation, the actuator lowers the electrodes 42, 44 and pushes the electrodes 42, 44 into the soil mass 30. The electrodes 42, 44 may include force/pressure sensors such that when a pre-determined force (i.e. a maximum allowable force) pushes against the electrodes 42, 44 are detected, or when the actuator has been extended to its maximum stroke length, the current and voltage measurements are initiated automatically after 1-5 seconds (the exact delay time be pre-determined by the user). The pre-determined delay time is to provide for a complete electrical circuit to be established before any measurements are taken.

[0080] In some embodiments, five (5) continuous current and voltage measurements may be taken at an interval of 1-3 seconds (pre-set by a user). The measured values are data logged and saved into a designated folder with a file name predefined by the user.

[0081] After the at least one image of the soil mass 30 and/or the soil parameter measurement(s) have been received from the data acquisition module 62, the data analysis module 64 operates to analyse the data.

[0082] In some embodiments, the acquired image or images are processed by the data analysis module 64 in accordance with the following image processing method 70 (see Figure 7) as exemplified in the following steps.

[0083] Step s72: Extraction of RGB Values from each image. Data analysis module 64 extracts the acquired image's RGB (red, green, blue) value and stores it in a data storage (which may be a database) arranged in data communication with

module 64.

[0084] Step s74: Conversion to Greyscale. The RGB image is converted into a greyscale image of a particular resolution, such as an 8-bit grayscale image using a weighted conversion method expressed in equation 2:

$$8bit = 0.299 * Red + 0.587 * Green + 0.114 * Blue \quad (2)$$

Where

Red is the red value of a pixel

Green is the green value of a pixel

Blue is the blue value of a pixel

- 5 After conversion from the RGB image to 8-bit greyscale, the processed 8-bit greyscale image file may be then stored into the processor's hard drive according to a custom file extension.

- [0085]** Step s76: Computation of a co-relation matrix. A second-order statistical texture method, the Grey Level Co-Occurrence Matrix (GLCM) assumes that
10 texture information can be characterised by a tabulation of the frequency of occurrence of different combinations of pixel brightness values, or grey levels, in an image. The matrix takes the form of a second-order joint conditional probability density function, $P(i, j)_{d, \theta}$. Consider a pair of pixels (x_1, y_1) and (x_2, y_2) , with grey levels i and j respectively, which are found at distance d apart in direction θ with
15 respect to the horizontal axis (see Figure 8). $P(i, j)_{d, \theta}$ is the probability that grey level i and grey level j co-occur for a given distance d and direction θ measured anti-clockwise from the horizontal axis. The direction θ can be chosen from any of the eight possible directions of adjacency, but 0° and 180° result in equivalent pixel pairs; so do 45° and 225° , 90° and 270° , and 135° and 315° . Hence, four principal
20 values of θ corresponding to $= 0^\circ, 45^\circ, 90^\circ$, and 135° may be used. Relations that are spatially invariant, if desired, can be obtained, by averaging the counts in all four directions. The distance between the reference and neighbour pixel, d , is also known as the displacement of the GLCM or GLCM step-size. Here, the distance is mathematically defined in equation 3.

$$d = \max(|x_1 - x_2|, |y_1 - y_2|) \quad (3)$$

Where

d is the distance between the reference and neighbour pixels

x_1 is the x-coordinate of the reference pixel

y_1 is the y-coordinate of the reference pixel

x_2 is the x-coordinate of the neighbour pixel

y_2 is the y-coordinate of the neighbour pixel

The co-occurrence matrix $P(i, j)$ is then constructed by counting the number of pixel pairs with grey levels i and j for the specified d and θ . If an image has g grey levels, then the GLCM can be written as a $g \times g$ matrix with g^2 elements. In this research, greyscale images with grey levels of 0 – 255 were used. The dimension of the computed GLCM is $256 \times 256 = 65,536$. The matrix is then normalised by:

$$p(i, j) = \frac{P(i, j)}{\sum_{i,j}^g P(i, j)} \quad (4)$$

$p(i, j)$ is the normalised co-occurrence matrix

$P(i, j)$ is the co-occurrence matrix for a given d and θ

Default values for distance d and direction θ may be pre-determined or pre-set. In some embodiments, the default values are 1 and 0° respectively. These values can be changed when required.

[0086] Step s78: Computation of Haralick Texture Features. From the GLCM, fourteen (14) Haralick Texture Features can be computed. In some embodiments, five (5) main Haralick Texture Features are used and can be computed based on the equations as illustrated in Figure 9 (also referred to as GLCM textural features). The Texture Features are as follows.

(i.) Angular Second Moment (ASM);

(ii.) Contrast (CON);

(iii.) Correlation (COR);

(iv.) Entropy (ENT); and

(v.) Inverse Difference Moment (IDM).

The five Haralick Texture Features are arranged as inputs for decision-making, i.e. arranged as inputs of the decision-making module 66.

[0087] In addition to or as an alternative to the image processing method 70, the data analysis module 64 may operate to calculate a soil apparent electrical resistivity indicator based on equation (1). As the soil mass is unlikely to be uniform, an average measurement value taken over a few measurements (at different locations or varying depth) may be obtained for a more reliable result compared to a single measurement value.

[0088] After the image data and soil apparent electrical resistivity indicator have been calculated and/or determined, the decision-making module 66 is utilized to initiate the classification of soil type based on a decision-making algorithm. The decision-making algorithm may be a probabilistic decision-making algorithm or a user-defined decision-making algorithm. It is appreciable that a variety of decision making algorithms may be utilized. Non-limiting examples include machine-learning algorithm, self-organizing maps, expert rule-based systems, fuzzy-logic modelling, evolutionary algorithms, and/or combinations of one or more of the aforementioned. It is appreciable that the decision-making algorithms may be combined and executed in sequence or in parallel.

[0089] In some embodiments, the machine learning algorithm may include an artificial neural network (ANN). The user-defined algorithm may include the soil electrical resistivity analysis as derived from equation (1).

[0090] It is appreciable that the ANN model may be trained based on a supervised or unsupervised learning model using various classification and/or regression methods. The training may be achieved using a sample of soil images stored within one or more databases which may be arranged in data or signal communication with the processor 60 (via wired or wireless channels). The sample of soil images, also referred to as training samples, are stored with known soil properties that have been determined from conventional soil tests. In general, the larger the samples the more reliable the results. Nevertheless, beyond a certain sample size no noticeable improvements in accuracy or reliable of results may be

noted, and there may be possibility of over-training.

[0091] With the Haralick Texture Features obtained from the step s78 as inputs to the decision-making module 66, the trained ANN model computes the probability values of “Good Earth” and “Soft Clay” for the soil mass. In some embodiments the probabilistic model may be formed in accordance with rules as listed below: -

(a.) If there are no inputs due to hardware issues (e.g. no image captured, blockage of camera etc.), then the ANN Result is *No Input*

(b.) If the probability of “Good Earth” is significantly higher than probability of “Soft Clay”, then the ANN Result is *“Good Earth”*

(c.) If the probability of “Soft Clay” is significantly higher than probability of “Good Earth”, then the ANN Result is *“Soft Clay”*

(d.) If there is no probability that is significantly higher, then the ANN Result is *Indistinctive*

[0092] The definition of significantly higher may be pre-determined by a user. In some embodiments, the difference in probability may be larger than a value between 0.2 and 0.5 to qualify as ‘significantly higher’.

[0093] In addition to or as an alternative to the ANN model, the apparent electrical resistivity of the soil mass may be used as an input to the decision-making module 66. If the apparent electrical resistivity of the soil mass falls within the range for “Good Earth”, the soil mass will be classified as “Good Earth”; and similarly, for “Soft Clay”. In some embodiments the user-defined model may be formed in accordance with rules as listed below: -

(a.) If there are no inputs due to hardware issues (e.g. no resistivity measured, no electrical current generated etc.), then the Electrical Resistivity Result is *No Input*

(b.) If the apparent electrical resistivity falls within the “Good Earth” range, then the Electrical Resistivity Result is *“Good Earth”*

(c.) If the apparent electrical resistivity falls within the “Soft Clay” range,

then the Electrical Resistivity Result is “*Soft Clay*”

(d.) If the apparent electrical resistivity falls right in between the “Good Earth” and “Soft Clay” range, then the Electrical Resistivity Result is *Indistinctive*

5 **[0094]** The range of electrical resistivity may be pre-determined by a user. In some embodiments, the range between 0 and a pre-determined number may qualify as Soft Clay, and the range beyond the pre-determined number may qualify as Good Earth. This pre-determined number may be between 20 Ohm-metres (Ωm) and 100 Ωm for some types of soil.

10 **[0095]** The final decision matrix as shown in Figure 10 for classification of the soil mass 30 may be based on the results obtained from the ANN model and/or results obtained from the electrical resistivity results in accordance with a decision-making rule base as follows: -

(a.) If both inputs are the same,

15 (i) If both are No Input, then the Final Output is No Input

(ii) If both are “Good Earth” (GE), then the Final Output is GE

(iii) If both are “Soft Clay” (SC), then the Final Output is SC

20 (iv) If both are Indistinctive, then the Final Output is Mixture (i.e. the soil mass is a mixture of approximately equal proportions of Good Earth and Soft Clay)

(b.) If both inputs contradict (i.e. one is “Good Earth”, one is “Soft Clay”), then the Final Output is “Requires User’s Discretion” (i.e. geotechnical engineering judgment is required)

(c.) If either input has No Input,

25 (i.) If the other input is “Good Earth” or “Soft Clay” or Indistinctive, then the Final Output is respectively GE (<Other Input> Only) or SC (<Other Input> Only) or Indistinctive (<Other

Input> Only)

(d.) If either input has Indistinctive,

(i.) And the other input is “Good Earth” or “Soft Clay”, then the Final Output is respectively GE (<Other Input> Only) or SC (<Other Input> Only)

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[0096] Overall Soil Classification. When the processor 60 has analysed the data, a graphical control element (e.g. a window as colloquially known) will pop up (Figure 11) via the GUI 68 to conclude the overall soil type, signifying the end of the soil classification process. Based on the decision-making framework, there are several possible classified results as shown in Figure 10.

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[0097] It is to be appreciated that the method of Figure 10 may be implemented in the form of a non-transitory computer readable medium containing executable software instructions thereon wherein when executed performs the method of identifying and classifying a soil mass comprising the steps of classifying a soil mass; wherein the classification step includes classifying the soil mass to one of at least two soil types.

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[0098] In some embodiments, the method of classifying a soil type includes the following steps: - (a.) moving an image acquisition module and a soil parameter measurement device towards a soil mass; (b.) acquiring an image of the soil mass; (c.) measuring the soil parameter of the soil mass; (d.) sending the image and parameter measurement to a processor; (e.) conducting data analysis; (f.) classifying by the processor the soil mass based on data analysis; wherein the classification step includes classifying the soil mass to one of at least two soil types. The method may be implemented on a processor to control the apparatus 10.

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[0099] It should be appreciated by the person skilled in the art that the above invention is not limited to the embodiment described. In particular, various embodiments may be applied to the classification of other soil types or soil mixed with other materials such as sludge waste. It is appreciable that modifications and improvements may be made without departing from the scope of the present

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invention.

[00100] It should be further appreciated by the person skilled in the art that one or more of the above modifications or improvements, not being mutually exclusive, may be further combined to form yet further embodiments of the present invention.

CLAIMS

1. An apparatus for classification of a soil mass including

an image acquisition module having at least one light source;

a soil parameter measurement device to measure a parameter associated
5 with a soil type, and

a drive operable to move the image acquisition module and/or soil parameter
measurement device along at least one axis.
2. The apparatus of claim 1, wherein the image acquisition module includes a
camera and a distance sensor.
- 10 3. The apparatus of claim 1 or 2, wherein the at least one light source is a white
light source with colour temperature between 3000 K and 4000 K.
4. The apparatus of claim 3, wherein the white light source includes a plurality of
LED flood lights.
5. The apparatus of claim 4, wherein there comprises 124 LED flood lights.
- 15 6. The apparatus of claim 2, wherein the distance sensor is a laser distance
sensor.
7. The apparatus of claim 6, wherein the distance sensor is operable to detect
distances of between 0.5 metres (m) and 1.2 m.
8. The apparatus of claim 1, wherein the soil parameter measurement device is
20 a soil electrical resistivity sensor having a plurality of probes.
9. The apparatus of claim 8, wherein the plurality of probes include a first set of
two probes for sending an electrical current into a soil, and a second set of two
probes for measuring the electrical potential between the second set of two probes.
10. The apparatus of claim 1, wherein the soil parameter measurement device
25 includes a moisture probe.
11. A system for classification of soil mass including

an image acquisition module for obtaining at least one image of a soil mass;

a soil parameter measurement module for measuring a parameter of the soil mass; and

5 a processor operable to receive the at least one image and the soil mass measurement(s);

wherein the processor includes a classification module operable to classify the soil mass to one of at least two soil types.

12. The system of claim 11, wherein the classification module includes a first module to classify the soil mass based on a machine learning algorithm, and a
10 second module to classify the soil mass based on the soil parameter measurement.

13. The system of claim 12, wherein the machine learning algorithm is based on an artificial neural network.

14. The system of any one of claims 11 to 13, wherein the at least two soil types includes Good Earth and Soft Clay.

15 15. The system of any one of claims 11 to 14, wherein classification of the soil mass based on the soil parameter measurement is activated if the machine learning algorithm is unable to classify the soil mass.

16. The system of any one of claims 11 to 15, wherein the soil parameter measurement module includes a moisture probe and a soil electrical resistivity
20 sensor.

17. A method for classification of a soil mass including the steps of:- (a.) moving an image acquisition module and a soil parameter measurement device towards a soil mass ; (b.) acquiring an image of the soil mass ; (c.) measuring the soil parameter of the soil mass ; (d.) sending the image and parameter measurement to
25 a processor; (e.) conducting data analysis; (f.) classifying by the processor the soil mass; wherein the classification step includes classifying the soil mass to one of at least two soil types.

18. A processor having an input module to receive a first set of soil images and a

second set of soil parameter measurements wherein the processor includes a classification module operable to classify the soil mass to one of at least two soil types.

19. A non-transitory computer readable medium containing executable software
- 5 instructions thereon wherein when executed performs the method of identifying and classifying a soil mass comprising the steps of:- (a.) moving an image acquisition module and a soil parameter measurement device towards a soil mass; (b.) acquiring an image of the soil mass; (c.) measuring the soil parameter of the soil mass; (d.) sending the image and parameter measurement to a processor; and (e.)
- 10 classifying by the processor the soil mass; wherein the classification step includes classifying the soil mass to one of at least two soil types.