Method for Mapping Geometrical Features Using Opto-Electronic Arrays

Background of Invention

Field of the Invention

[0001] The invention relates generally to systems and methods for mapping geometrical features. In particular, embodiments of the present invention relate to systems and methods for inspecting screens used in oil and gas industry.

Background Art

[0002] In the drilling of oil wells, referring to FIG. 1, typically a wellbore **12** is drilled throw a geological formation **14** containing fluids such as oil. The wellbore **12** is protected with a casing **16** having perforations **18** through which fluids flow from formation **14** into the wellbore **12**. The fluids are pumped out of the wellbore using any artificial lift, such as gas lift or a pumping system **10**, which may be an electro-submersible pump, progressive cavity pump, rod pump, hydraulic jet pump, or diaphragm pump. The fluids flowing into the wellbore often include undesirable particles such as sand, which may result in inefficient oil production due to obstruction of fluid flow, wearing of the pumping system, and casing failure caused by formation corrosion. Therefore, sand control is often necessary.

[0003] In order to control sand, usually a sand screen is placed in the wellbore to screen out the sand particles while allowing the fluids to flow through. As shown in FIG. 1, a packer **13** may be used to isolate the pumping system **10** from the completion. The packer **13** has a sand screen **15** attached thereto. Under the action of drawdown produced by the pumping system **10**, fluids are forced through the sand screen **13**. One of the most commonly used screens is a wire-wrapped

screen, formed by helically wrapping wires around a length of perforated base pipe. Sand screens may be attached to a packer that protects a pumping system (as shown in FIG. 1) or to a production string deployed in the production zone. Wire wrapped screens may be used, alone or in combination with gravel-packing, either in open-hole or in cased-hole. A method of constructing wire-wrap well screens has been described in U.S. Patent Application Pub. No. 2005/0125980.

[0004] The filtering performance is a direct function of the size of the gap between adjacent turns of wires as only particles smaller than the gap will be allowed to commingle with the fluid produced in the well. The gap also determines fluid flow efficiency because if the gap is too small, fluid flow may be restricted, and the screen may be clogged easily. Referring to FIG. 2A for a typical screen in the art, the gaps **21** between the long wires **22** are generally on the order of 100 microns, and the wire itself usually has a width on the order of 1 millimeter. Figure 2B illustrates a cross-sectional view of a screen. Wire-wrapped well screens may be of large size, and are often several tens of feet long. Thus, there are usually a large number (tens of thousands) of repetitive patterns within one screen.

[0005] Because the widths of gaps **21** between wires **22** are critical for sand control, it is important to inspect the screen in a fast and economical way and subsequently to maintain the screen. The gaps should be as uniform as possible throughout the screen. Conventional inspection techniques involve manual methods using a gauge or an optical scope to measure the gap widths. Due to the small sizes of the gap widths, usually an enlarged image from a magnifying lens is required in order to measure the widths. Some of these techniques have been disclosed, for example, in U.S. Patent No. 4,914,514. Conventional techniques are often inefficient and are subject to human errors. More recently, automated optical inspection methods have been disclosed, for example, in U.S. Patent Application Pub. No. 2004/0258293, which describes using a camera to capture

images of a portion of the screen to determine the distances between wires. Due to the large size of a screen, still only a subset of sample sections may be examined, and statistical techniques are often used to characterize the quality of a screen using quantities such as the average gap width and the statistical variance about the average.

[0006] Therefore, there still exists a need for new approaches for inspecting a screen or other large geometrical features in a fast, accurate, and economic way.

Summary of the Invention

[0007] One aspect of the invention relates to a method for inspecting a surface of an object, including scanning the surface using an array of opto-electronic sensors, obtaining a reflected light signal from a location on the surface, combining the light signals to form a representation of geometrical features of the surface, and processing the representation to obtain geometric quantities of the geometrical features.

[0008] In another aspect, embodiments disclosed herein relate to system and apparatuses for inspecting a well screen, including a sensor array made of a plurality of opto-electronic sensors, a motion control unit, and a processor.

[0009] Other aspects and advantages of the invention will become apparent from the following description and the attached claims.

Brief Summary of the Drawings

[0010] FIG. 1 illustrates a typical wellbore for production of oil in the prior art.

[0011] FIG. 2A shows a close-up picture including an enlarged section of the surface of a wire-wrap screen in the prior art.

[0012] FIG. 2B shows a cross-sectional view of a section of a wire-wrap screen in the prior art.

[0013] FIG. 3 shows an exemplary inspecting system in accordance with embodiments of the present invention.

[0014] FIG. 4 illustrates a method of using a single sensor to scan in a direction parallel to a cylindrical object.

[0015] FIG. 5 illustrates a method of using a single sensor to scan around a cylindrical object.

[0016] FIGS. 6A and 6B illustrate a surface mapping method using an array of sensors to scan in a direction parallel to a longitudinal axis of an elongated object.

[0017] FIGS. 7A and 7B illustrate a surface mapping method using an array of sensors to scan in a direction around a longitudinal axis of an elongated object.

[0018] FIG. 8 illustrates exemplary operations for a well screen inspection using a opto-electronic sensor array.

[0019] It is to be understood that the drawings are to be used for the purpose of illustration only, and not as a definition of the metes and bounds of the invention, or as a basis for reading non-existent or un-recited limitations into the claims.

Detailed Description

[0020] In one aspect, embodiments of the present invention relate to methods for inspecting geometrical features of composite assemblies, such as filters and screens used in the oil and gas industry. The method and system in accordance with embodiments of the present invention can also be applied to inspecting other structures having a large number of generally repetitive patterns, such as pre-perforated flat or cylindrical products, woven metallic or non-metallic compositions, corrugation or embossing.

[0021] Embodiments of the present invention employ a plurality of opto-electronic sensors that form an array. The sensors may include laser sensors or

machine vision cameras, or a combination of both. When using a laser sensor, a laser produces a small light spot on the surface to be inspected. A discontinuity on the surface, *i.e.*, a gap between wires, results in a loss of a light spot. Such an event can trigger a mark, which can be recorded along with motion coordinates provided by a motion control unit. With proper calibration, the adjacent marks are then combined into a digital geometric image. In accordance with some embodiments of the invention, a photo-detector in the array detects the brightness of the light spot. A map of the brightness can be generated during the scan and can be used to analyze geometrical features of the surface.

[0022] When using machine vision cameras, a motion control unit moves the object to be inspected, or moves a camera or a plurality of cameras to scan the surface and record an image of the surface. Processing of digital pixels combined with an adequate calibration of the system is then translated into quantitative 2-D information. In addition, machine vision cameras may require a light source to illuminate the surface when natural lighting is not available.

[0023] For a single-axis linear array, when the surface to be inspected is flat, scanning is usually performed through a linear motion either parallel to the array axis or transverse to the array axis. When the surface is cylindrical, scanning is usually performed through a rotational motion around the cylinder axis. In accordance with some embodiments of the present invention, scanning may also be performed by successive iterations of linear and/or rotational motions.

[0024] An exemplary surface inspection system is illustrated in FIG. 3. Although only three opto-electronic sensors **31**, **32** and **33** are shown here to form an array **300**, it will be recognized by those skilled in the art that the array may include any number of sensors. In the case that the sensor **31** comprises a laser, the laser sends out a laser beam **34** and illuminates a spot on the surface **35** to be examined. The reflected light signal is captured by a photo-detector in the array

300. Although the sensors **31**, **32** and **33** shown in FIG. 3 are mechanically linked together and move collectively, in accordance with other embodiments of the present invention, the sensors can move independently. In this case, the independent motions are associated with independent position detections, so that an optical sensing is always associated with a spatial location.

[0025] The array **300** is shown to be attached to and is movable along a rail **36**. The rail **36** is movable along another rail **37**. During operation, the sensor array **300** is brought to a predetermined distance **d** from the surface **35**, and driven by a motor, the array **300** can move along the rail **36** in a direction **361**, and the rail **36** can move along the rail **37** in a direction **371**. Hence, the array **300** can move freely to scan the whole surface **35**. Furthermore, according to some embodiments, the array **300** may rotate around an axis **38**, as shown by the arrow **381**. An individual sensor **33** may also rotate, as indicated by the arrow **331**, around the linear axis of the array **300**. In this case, the sensor is capable of scanning an area away from the location closest to the sensor on the surface. In addition, the array **300** may be moving in the direction along the rail **36** and/or the rail **37**, and during the linear motion, the array **300** may be directed to rotate around the axis **38**, or rotate to a certain angle relative to the rail **36**, and individual sensors may also have the freedom to move. In most operations, the distance **d** is kept constant, *i.e.*, the array **300** generally scans the surface **35** in directions parallel to the surface **35**.

[0026] The motion of the array **300** is controlled by a motion control unit **107** within an electrical circuit **106**, which, in turn, may receive commands from a computer **11**. The electrical circuit **106** may also include an image processing unit **109**, which may also receive commands from the computer **11** for collecting data, receiving the relative positions of the array **300** and/or the surface **35**, and process the obtained images. The images may be displayed on the computer display **13**. In addition, the computer **11** may include readable media such as a CD-ROM

disks, floppy disks, hard-disk drives, and flash drives, which contain programs of instructions for controlling motion, collecting and storing data, processing images, and performing quantitative and statistical analysis.

[0027] Although FIG. 3 illustrates only one embodiment of the configuration for the array and the means for controlling motion, many other configurations and motion control means are known in the art and can be implemented in accordance with embodiments of the present invention. For example, the array **300** may be a 2-D array, and the motion may be achieved using a motor and a carriage or other mechanical means. In addition, the surface **35** to be inspected does not have to be in a fixed position. By moving the surface **35** and/or the array **300**, a relative motion between the surface **35** and the array **300** may be realized and the scan can be performed. In addition, the surface **35** does not have to be flat. Other shapes of surfaces, such as cylindrical surfaces may be examined. Various scanning options may be implemented, depending on the array topology and the complexity of the surface to be inspected.

[0028] In accordance with embodiments of the present invention, scanning motions do not have to be exhaustive over the entire screen. Instead, a random analysis protocol may be employed such that the scans cover only a representative fraction of the whole target area. Parameters governing the area sampling protocol may be entered by an operator and/or generated by a computer program. These parameters may also be automatically altered in the course of a scan process based on real-time measurement results. For example, if anomalies occur at a rate higher than a preset value, a higher-density random scanning may be triggered. In some cases, a 100% scan coverage may be triggered, at least in areas surrounding a detected anomaly.

[0029] Referring to FIG. 4, wherein a cylindrical surface **41** of a length L is to be inspected by a single sensor **42**. The sensor **42** may be directed to move

linearly along the axis of the cylindrical surface **41**, and the distance T is registered. In addition, as illustrated in FIG. 5, the sensor **42** may rotate around the axis of the cylindrical surface **41** while being at a fixed radius R from the axis. Alternatively, the sensor **42** may be at a fixed position and the surface **41** may be rotated while being scanned by the sensor **42**. In accordance with some embodiments of the present invention, both the sensor **42** and the surface **41** may be controlled to move in order to achieve a better scan efficiency. The relative scanning motion may have a fixed or a variable speed, and may be in continuous or discrete motion mode.

[0030] Figures 6A and 6B illustrate a surface mapping method using an array of sensors **61—64** to scan a cylindrical surface **66** of a length L. The sensors are spaced at a fixed distance SR from each other. As shown in FIG. 6B, only a fraction of motion with a distance T parallel to the longitudinal axis of the surface **66** is needed to cover the whole length L of the surface **66**. In addition, the sensors can be controlled to rotate around the cylindrical surface **66**, or alternatively the cylindrical surface **66** can rotate around its axis, or both the sensors and the surface are in motion, so long as a relative motion is achieved to perform a desired scan. The relative scanning motion may have a fixed or a variable speed, and may be in continuous or discrete motion mode. The sensors in the array do not have to move collectively as shown in the exemplary configuration in FIGS. 6A and 6B. The sensors may be controlled to move individually to achieve a desired scan.

[0031] Figure 7A illustrates an array of sensors **71—73** arranged at a constant distance around a cylindrical surface **77**. The distance between the sensors may also have a fixed value SR. Sensors **71—73** capture light reflected from #1, #2, and #3, respectively, on the surface **77**. As shown in FIG. 7B, the relative motion between the sensors and the surface does not need to be a full circle. Only a half circle of relative motion caused by rotating the surface, or by rotating the sensor

array, or both, is sufficient to cover the whole circle including locations #4, #5, and #6. The sensors may be pre-configured to be mechanically and/or electrically linked so that they act as a single entity during the array/surface relative motion. In such a case, only one motion control per axis is needed. The sensors may also be pre-configured during an initialization phase. They move and self-adjust their relative locations and positions while the scanning is being performed.

[0032] Exemplary operation steps for inspecting a well screen are illustrated in FIG. 8. At step **90**, the screen and/or the sensor array are positioned such that the sensor array points to a starting location on the screen to be inspected. Geometrical parameters, such as the size of the screen, are initialized at step **91**. This step may include data entry from a manufacturing database, data entry from an operator, and initial measurements during the initial setup phase. The coordinates of the location are registered, for example, by a computer at step **92**. This step may At step **93**, a light signal is obtained and recorded corresponding to the registered location. If a single laser beam is used as the lighting source, depending on the photo-detector/sensor type used, the light signal may be a digitized intensity signal or an image of a light spot. If an array is deployed, the light signal is an opto-electronic image covering an area around the location. A maximum number of scan steps may be specified, for example, using a maximum scan time period or a maximum size of the screen. If the maximum number of specified steps is reached as determined at step **94**, then at step **96** the light signals are combined to form an image, which is processed and quantitatively analyzed at step **97**. The analysis may include statistical analysis to obtain quantities such as the mean value of the size of the gaps in the screen and the variance of the size. If the maximum number of steps is not yet reached, the screen and/or sensor array are moved to a next location at step **95**, and steps **92-94** are repeated.

[0033] In accordance with some embodiments of the present invention, an array may include a plurality of sensing units. Each unit as well as individual sensors

may move independently. A combination is thus possible using a master motion of the array as a whole, while each sensing unit may have an independent location adjustment. This method allows a sensing unit to pause for a fraction of time while the whole array is in continuous motion while scan is being performed.

[0034] Advantages of the present invention may include one or more of the following: (a) faster scanning; (b) larger coverage area; (c) higher measurement accuracy when a small laser spot is used; (d) flexibility with independent movement of individual sensors in the array.

[0035] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be advised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

Claims

What is claimed is:

1. A method for inspecting a surface of an object, comprising:

scanning the surface using an array of opto-electronic sensors, wherein the opto-electronic sensors are separate units arranged in a spaced-apart configuration in the array;

obtaining a plurality of reflected light signals from a plurality of locations on the surface;

combining the plurality of light signals to form a representation of geometrical features of the surface; and

processing the representation to obtain geometric quantities of the geometrical features.

2. The method of claim 1, wherein the scanning is performed through a relative motion means that causes a relative motion between the array and the surface by moving at least one of the surface and the array, and wherein the relative motion is at least one of a continuous motion and a discrete motion.

3. The method of claim 2, wherein the relative motion is controlled by a motion control unit and is at least one selected from the group consisting of linear motion parallel to the array axis, linear motion transverse to the array axis, and rotational motion around a cylindrical object axis.

4. The method of claim 3, wherein the sensors are pre-configured to move collectively.

5. The method of claim 3, wherein the sensors move independently.

6. The method of claim 1, wherein the surface is a wire-wrap sand screen surface for use in subsurface wells.

7. The method of claim 1, wherein the representation is a digital representation and said processing utilizes digital image processing.

8. The method of claim 1, wherein said processing comprises performing statistical analysis to obtain a mean value of a geometric quantity and a statistical variance about the mean value.

9. The method of claim 1, wherein the array of opto-electronic sensors comprises at least one laser and one photo-detector.

10. The method of claim 9, wherein said obtaining comprises using the photo-detector to detect a light spot on the surface illuminated by the laser.

11. The method of claim 10, wherein said combining the plurality of light signals comprises interpreting a lack of light spot as a discontinuity in the surface.

12. The method of claim 11, wherein said combining the plurality of light signals further comprises registering a coordinate in the surface provided by a motion control unit.

13. The method of claim 9, wherein said obtaining comprises detecting a brightness of a light spot on the surface illuminated by the laser.

14. The method of claim 13, wherein said combining the plurality of light signals comprises constructing a map of brightness.

15. The method of claim 1, wherein the array of opto-electronic sensors comprises at least one machine vision camera.

16. The method of claim 15, wherein the camera is a CCD camera, and wherein said obtaining comprises recording an image of a portion of the surface, and wherein said processing comprises digital processing of CCD pixel readouts and a calibration of a relationship between a distance between CCD pixels and the geometric quantities.

17. The method of claim 1, further comprising:

scanning a representative fraction of the surface based on a scan protocol;

detecting a frequency of occurrence of anomalies based on a statistical analysis; and

revising the scan protocol based on the detected frequency of occurrence of anomalies.

18. A system for inspecting a surface of an object, comprising:

an array of opto-electronic sensors, wherein the opto-electronic sensors are separate units arranged in a spaced-apart configuration in the array;

a motion control unit for causing a relative motion between the surface of the object and the array; and

a computer system configured to perform operations comprising:

controlling the relative motion between the surface and the array via the relative motion unit;

registering a location of the array relative to the surface;

capturing an image representation of geometrical features of the location on the surface using the array;

calibrating a relation between a size of the image representation and a size of a geometrical feature on the surface; and

calculating the size of the geometrical feature based on the captured image representation and the calibrated relation.

19. An apparatus for inspecting a well screen, comprising:

a sensor array comprising a plurality of opto-electronic sensors, wherein the opto-electronic sensors are separate units arranged in a spaced-apart configuration in the array;

a motion control unit for controlling a relative motion between the well screen and the sensor array and for registering a coordinate of a location of the array relative to the well screen; and

a processor for obtaining a geometric quantity of the well screen based on an image obtained by the sensor array and the location registered by the motion control unit.

20. The apparatus of claim 19, wherein the plurality of opto-electronic sensors move together.

21. The apparatus of claim 19, wherein the plurality of opto-electronic sensors move independently of each other.

22. The apparatus of claim 19, wherein the opto-electronic sensors comprise a plurality of lasers and photo-detectors.

23. The apparatus of claim 19, wherein the opto-electronic sensors comprise at least one CCD camera.

24. The apparatus of claim 19, wherein the array further comprises a plurality of sensing units, and wherein the sensing units move independently.