



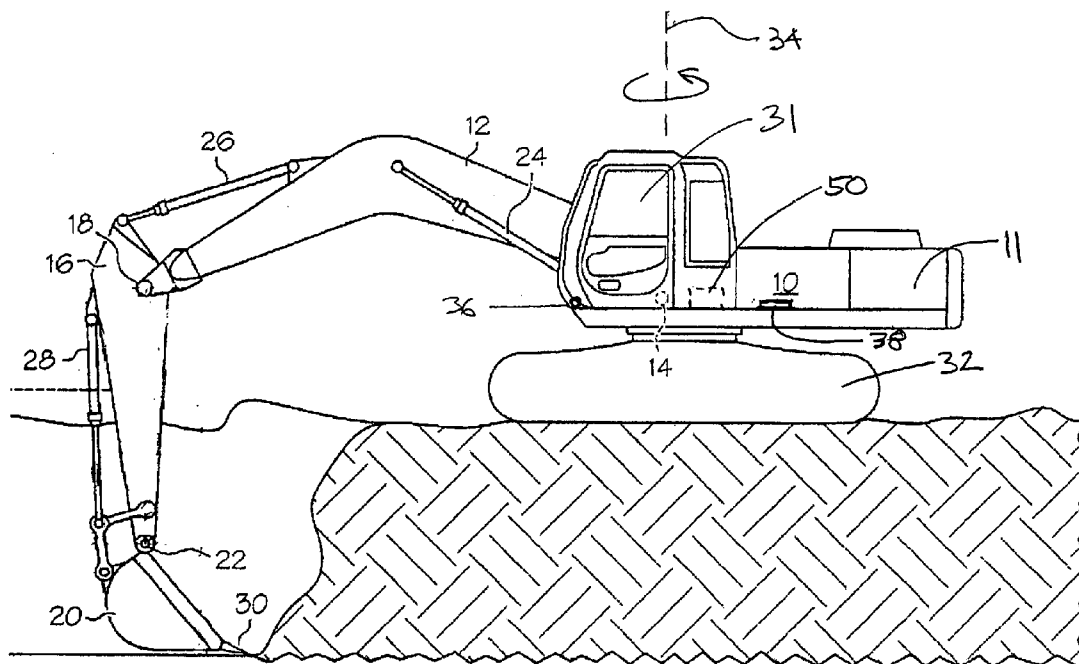
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(19) **United States**(12) **Patent Application Publication**
Green(10) **Pub. No.: US 2008/0000111 A1**(43) **Pub. Date: Jan. 3, 2008**(54) **EXCAVATOR CONTROL SYSTEM AND METHOD**(76) Inventor: **Francisco Roberto Green,**
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DAYTON, OH 45402-2023**(21) Appl. No.: **11/478,389**(22) Filed: **Jun. 29, 2006****Publication Classification**(51) **Int. Cl.**
E02F 5/02 (2006.01)(52) **U.S. Cl.** **37/348**(57) **ABSTRACT**The system determines the orientation, r , of an excavator or other machine sitting on a sloped portion of-a construction

or work site with respect to the direction across the site in which there is no slope. This direction across the site in which there is no slope is perpendicular to the direction of the fall line of the sloped portion. The system includes a first inclinometer for determining the pitch angle, Pitch, of the machine and providing a pitch angle output. The system includes a second inclinometer for determining the roll angle, Roll, of the machine and for providing a roll angle output. Finally, the system includes a processor, responsive to said pitch angle output and said roll angle output, with the processor determining the orientation, r , according to one of the following: $r = \sin^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}]$; or $r = \cos^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}]$; or $r = \tan^{-1} [\text{Pitch}/\text{Roll}]$. The first and second inclinometers may comprise a single, dual axis inclinometer, or they may comprise a pair of appropriately oriented inclinometers. The system may use only one of the three formulae continuously, or may select various ones of the formulae for use at various times, depending upon which formula is judged to provide the most accurate indication of orientation. For example, the formula may be selected based upon the quadrant in which the longitudinal axis of the machine is oriented.



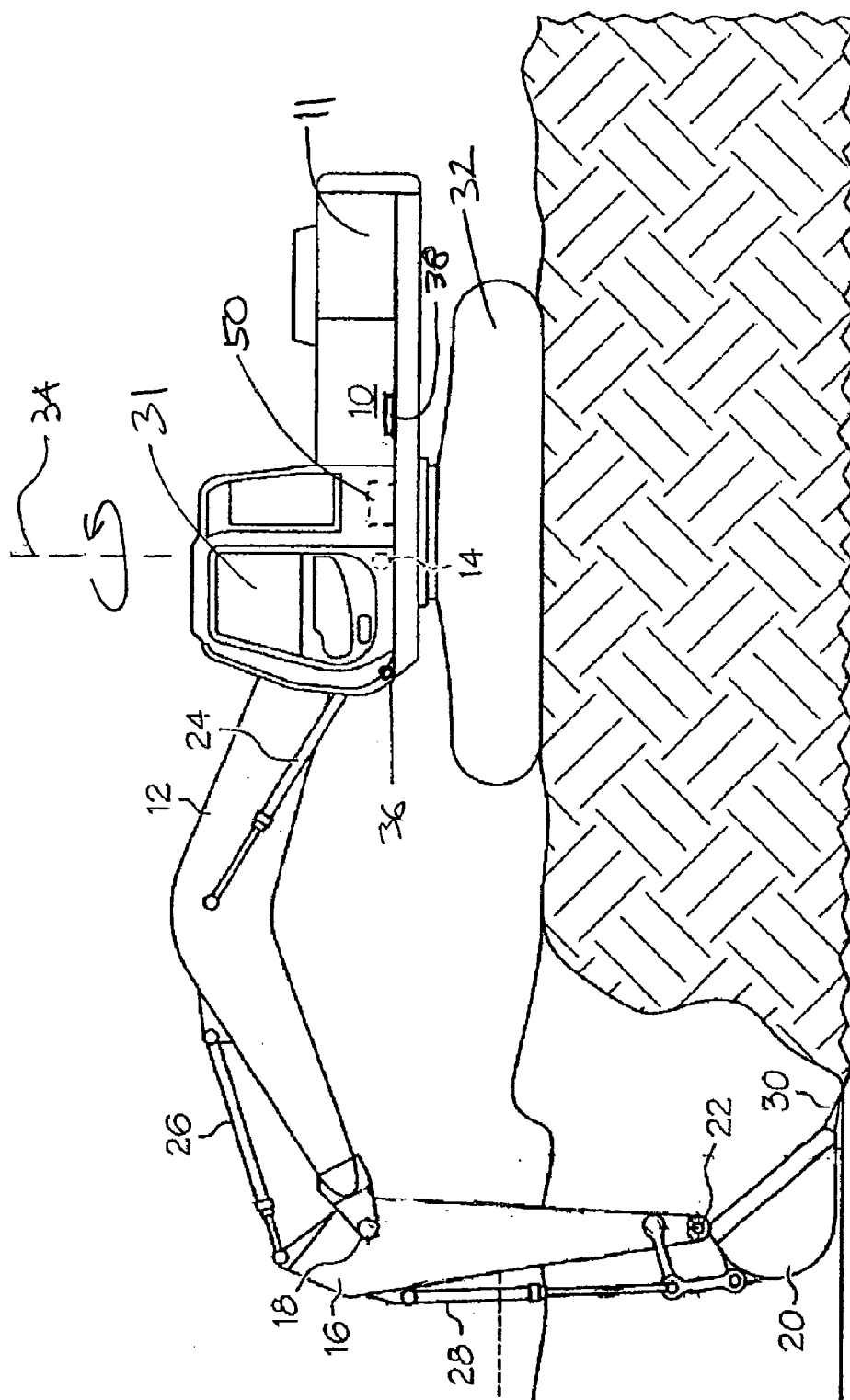


FIG. 1

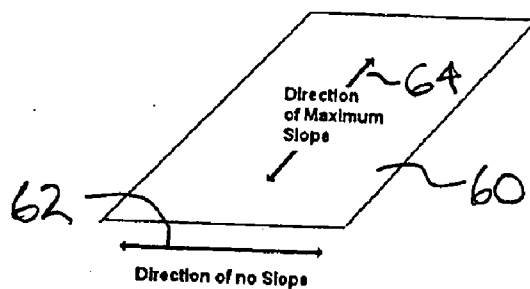


FIG. 2

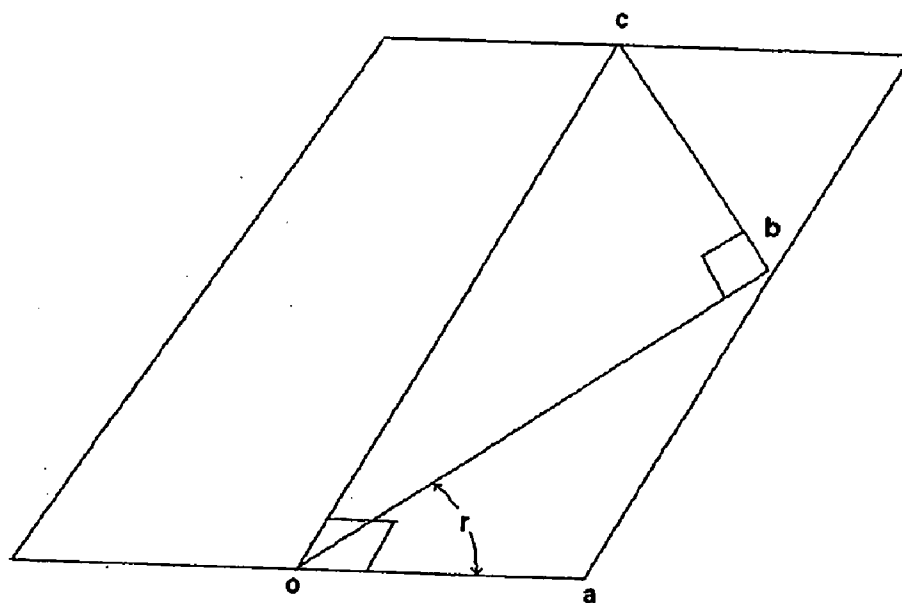


FIG. 3

EXCAVATOR CONTROL SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

BACKGROUND OF THE INVENTION

[0003] The present invention relates to excavators and similar types of machines and, more particularly, to a system and method for determining the orientation of the machine or a part of the machine without necessitating the use of additional sensors, detectors or receivers.

[0004] Excavators are used for excavating at construction sites, quarries, agricultural sites, and similar environments. To control an excavator with precision, it is important to know the position and the orientation of the excavator, including its cab, its boom, its dipper stick, and its bucket. A number of different arrangements have been used to collect this information. For example, a GPS antenna and receiver provide information as to the location of the excavator in three dimensions. However, a single GPS receiver and antenna cannot provide information about the orientation of the excavator, nor of the relative positions of the various components of the excavator.

[0005] It is known to use sensors at each of the joints between the cab structure and the boom, between the boom and the dipper stick, and between the dipper stick and the bucket, thereby providing relative angular positions. The control system of the excavator typically knows the location of the excavator from the GPS system. The control system further knows the orientation of the cab and chassis with respect to vertical, i.e., whether the cab is oriented with a non-zero roll angle (side-to-side) or a non-zero pitch angle (front-to-back). However, the rotation of the cab and chassis on the undercarriage leaves the control system without information as to the direction that the cab is aligned with unless a compass with a read-out is mounted on the cab. The use of additional sensors complicates the system and, at the same time, increases its cost and the likelihood of a malfunction. Further, an orientation arrangement relying on a compass sensor or the like may be subject to errors, since it may be adversely affected by the metal components and the electromagnetic fields that are common at work sites.

[0006] Accordingly, it is seen that there is a need for a control system and method for control of an excavator, or the like, in which the orientation of the excavator is determined without the need for additional sensors and further components.

SUMMARY OF THE INVENTION

[0007] The need is met by a system and method according to the present invention for determining the orientation, r , of an excavator sitting on a sloped portion of a construction site with respect to the direction of zero cross-slope. This direction across the site in which there is no slope is perpendicular to the direction of the fall line. The system includes a first inclinometer for determining the pitch angle, Pitch, of the excavator and for providing a pitch angle

output. The system includes a second inclinometer for determining the roll angle, Roll, of the excavator and for providing a roll angle output. Finally, the system includes a processor, responsive to the pitch angle output and the roll angle output, with the processor determining the orientation, r , of the pitch axis of the machine according to one of the following: $r = \sin^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}]$; or $r = \cos^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}]$; or $r = \tan^{-1} [\text{Pitch}/\text{Roll}]$. The first and second inclinometers may comprise a single, dual axis inclinometer, or they may comprise a pair of appropriately oriented inclinometers.

[0008] The system may use only one of the three formulae continuously, or may select among the formulae for use at various times, depending upon which formula is judged to provide the most accurate indication of orientation. The formula may be selected based upon the quadrant in which the excavator is oriented. The processor may select a cosine formula when the orientation of the excavator is near $\pm 90^\circ$, and a sine formula when the orientation of the excavator is near 0° or near 180° .

[0009] The method for determining the orientation, r , of an excavator sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, may comprise the steps of:

[0010] determining the pitch angle with respect to gravity, Pitch, of the excavator and providing a pitch angle output,

[0011] determining the roll angle with respect to gravity, Roll, of the excavator and for providing a roll angle output, and

[0012] determining the orientation, r , of the pitch axis of the excavator according to a selected one of the relationships:

$$r = \sin^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \cos^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \tan^{-1} [\text{Pitch}/\text{Roll}].$$

[0013] The roll axis of the machine may also be used as the reference axis, in which case the three prior equations become:

$$r = \sin^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}],$$

$$r = \cos^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ and}$$

$$r = \tan^{-1} [\text{Roll}/\text{Pitch}].$$

[0014] The step of determining the orientation, r , according to a selected one of the relationships includes the step of selecting among the relationships in dependence upon which relationship is likely to provide the most accurate indication of orientation. The steps of selecting among the relationships may include determining the quadrant in which the longitudinal direction of the excavator is found. A cosine formula may be used when the orientation of the excavator is near $\pm 90^\circ$, and a sine formula may be used when the orientation of the excavator is near 0° or near 180° .

[0015] It is an object of the present invention to provide a system for determining the orientation of an excavator with respect to a construction site without the need for sensors beyond those that are used on the excavator for other measurements. According to the present invention, the system and method contemplate determining the orientation of the excavator based on the measured pitch angle and mea-

sured roll angle of the excavator. The measured pitch and roll angles provide an indication of the orientation of the excavator with respect to the construction site. Other objects and advantages of the invention will be apparent from the following description, the accompanying drawings, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is a schematic drawing of an excavator incorporating the system of the present invention for determining the orientation of an excavator;

[0017] FIG. 2 is a schematic representation of a sloped work site; and

[0018] FIG. 3 is a schematic representation of a sloped work site, with that angular variables encountered in with an excavator incorporating the system of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0019] FIG. 1 depicts an excavator 10 of the type that may incorporate the system of the present invention for determining the orientation of the excavator sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion. The excavator includes a chassis 11, a boom 12 pivotally secured to the chassis 10 at a first pivot joint 14, a dipper stick 16 pivotally secured to the boom 12 at a second pivot joint 18, and a bucket 20 pivotally secured to the dipper stick 16 at a third pivot joint 22. Hydraulic cylinders 24, 26, and 28 are actuated to effect the relative movement of boom 12, dipper stick 16, and bucket 20, respectively. Bucket 20 includes a cutting edge 30 that may have serrated teeth. Bucket 20 may also have the freedom to tilt in the direction of the roll axis. The chassis 11 carries a cab 31 and is supported on an undercarriage support and transport 32 which may include track belts that facilitate the movement of the excavator 10 over the job site. The chassis 11 and the components it carries can be rotated about a generally vertical axis 34 with respect to the undercarriage support and transport 32 to place the bucket 20 at the precise location needed for excavation.

[0020] For the operator to control the operation of the excavator either manually or through an automated control system, information regarding the location and orientation of the excavator must be determined. The location of the excavator may be determined in any one of a number of ways, including using a laser positioning system, using a GPS positioning system, or using a system that combines laser and GPS positioning. The relative positions of the boom 12, the dipper 16, and the bucket 20 may be determined by angle encoders, gravity based inclinometers, or similar sensors associated with pivot joints 14, 18, and 22, or by string encoders associated with cylinders 24, 26, and 28, or by some combination of such sensors. The orientation of the excavator 10 with respect to true vertical is determined by inclinometers 36 and 38, which are mounted on the chassis 11. The inclinometer 36 provides an indication of the angle of roll and the inclinometer 38 provides an indication of the angle of pitch of the chassis 11. Similarly, it will be appreciated by those skilled in the art that roll inclinometer 36 and pitch inclinometer 38 may be mounted in the same housing, or even be the same sensor if the inclinometer is capable of measuring two directions at once, without detracting from the present invention.

[0021] It is also necessary to determine the direction with which the longitudinal axis of the excavator chassis is aligned. While it is possible to use a magnetic compass or a gyroscopic system to make this determination, the present invention accomplishes this without the need for such additional sensors and additional equipment. The system includes a processor 50 which retrieves the anticipated slope of the job site at the excavator's location, and then from the outputs of the inclinometers 36 and 38 determines whether the chassis 11 of the excavator 10 is oriented across the slope (zero pitch and maximum roll), up or down the fall line (maximum pitch and zero roll), or in some orientation in between these extremes.

[0022] Reference is made to FIG. 2, which simplistically shows a sloped plane 60 in space. It will be noted that the plane has two definite directions of interest—the direction of no slope 62, and the direction of maximum slope 64—and that these directions are always at right angles to each other. The job site on which the excavator is working will have previously been surveyed, prior to the operation of the system of the present invention, and these two orthogonal directions 62 and 64 will have been identified for each point on the surface of the job site. This information may have been stored in memory associated with and accessible by the processor 50.

[0023] As noted previously, the present invention includes two slope-sensing devices—inclinometers 36 and 38. These inclinometers change their orientation with respect to the surface of the job site as the chassis 11 rotates around axis 34, but they always remain perpendicular to each other. The values of the outputs from the inclinometers 36 and 38 may be designated "Roll" and "Pitch," respectively. Note that when one of these inclinometers is aligned with the direction of maximum slope, it measures maximum slope, while the other inclinometer measures zero slope. When the alignment of one of the devices moves away from the orientation of maximum slope, the slope measured by the device decreases from the maximum value of the slope.

[0024] Referring to FIG. 3, it will be seen that line oc represents the direction of maximum slope. Line oa represents the direction of zero slope. The direction ob indicates the orientation of the pitch axis with respect to the plane. The angle r indicates the rotation of the pitch axis of a machine from the zero slope direction of the plane, angle aob. Note that angles bco and aob are equal. Hence, the resulting slope measurement along the direction ob should be scaled by the sine of angle r:

$$\text{Pitch} = (\text{maximum slope}) * \sin(r).$$

[0025] Note that the roll axis is always orthogonal to the pitch axis. Hence, the roll axis is:

$$\text{Roll} = (\text{maximum slope}) * \sin(r \pm 90^\circ).$$

[0026] This is equivalent to:

$$\text{Roll} = (\text{maximum slope}) * \cos(r).$$

[0027] These equations imply the following:

$$\text{maximum slope} = (\text{Pitch}^2 + \text{Roll}^2)^{1/2}.$$

[0028] Therefore, to determine the rotation of the machine axis relative to the zero axis of the plane, r, any of the following equations may be used:

$$r = \sin^{-1} [\text{Pitch} / (\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \cos^{-1} [\text{Roll} / (\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \tan^{-1} [\text{Pitch} / \text{Roll}].$$

[0029] There may be benefits to using one equation over the other two, depending upon what quadrant the longitudinal axis of the excavator chassis is positioned in. The sine function is more sensitive than the cosine function for angles around 0° and 180°. Similarly, the cosine function is more sensitive than the sine function for angles around ±90°. By noting the sine and cosine functions, the quadrant in which the longitudinal axis is located may be determined.

[0030] It will be appreciated that the selection of the pitch axis of the machine as the reference is arbitrary. The roll axis of the machine may also be used as the reference axis, in which case the three prior equations become:

$$r = \sin^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}],$$

$$r = \cos^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ and}$$

$$r = \tan^{-1} [\text{Roll}/\text{Pitch}].$$

[0031] The direction of zero slope is, in a sense, arbitrary to the work site. Even though the calculation determines the absolute angle of the machine axis from the zero slope direction, it can only be used for relative reference.

[0032] It will be appreciated that if the excavator is on a level plane, no directional information can be determined. It will also be appreciated that this relative position determination may be made even if the work site has not previously been surveyed to determine the orientation of the zero slope direction relative to absolute directions.

[0033] One method would be to bench the excavator in a desired orientation. The relative orientation of the desired location would then be committed to memory associated with and accessible with processor 50 and used by said processor as a reference for the work site. It will be appreciated by those skilled in the art that multiple orientations could be benched and committed to the same memory for different modes of operation.

[0034] Having thus described the apparatus and method of the present invention in detail and by reference to preferred embodiments thereof, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims.

What is claimed is:

1. A system for determining the orientation, r , of an excavating machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising:

- a first inclinometer for determining the pitch angle, Pitch, of the excavating machine and providing a pitch angle output,
- a second inclinometer for determining the roll angle, Roll, of the excavating machine and for providing a roll angle output, and
- a processor, responsive to said pitch angle output and said roll angle output, said processor determining the orientation, r , of the pitch axis of the excavating machine according to the following:

$$r = \sin^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}].$$

2. A system for determining the orientation, r , of an excavating machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising:

- a first inclinometer for determining the pitch angle, Pitch, of the excavating machine and providing a pitch angle output,
- a second inclinometer for determining the roll angle, Roll, of the excavating machine and for providing a roll angle output, and
- a processor, responsive to said pitch angle output and said roll angle output, said processor determining the orientation, r , of the pitch axis of the excavating machine according to the following:

$$r = \cos^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}].$$

3. A system for determining the orientation, r , of an excavating machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising:

- a first inclinometer for determining the pitch angle, Pitch, of the excavating machine and providing a pitch angle output,
- a second inclinometer for determining the roll angle, Roll, of the excavating machine and for providing a roll angle output, and
- a processor, responsive to said pitch angle output and said roll angle output, said processor determining the orientation, r , of the pitch axis of the machine according to the following:

$$r = \tan^{-1} [\text{Pitch}/\text{Roll}].$$

4. A system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising:

- a first inclinometer for determining the pitch angle, Pitch, of the machine and providing a pitch angle output,
- a second inclinometer for determining the roll angle, Roll, of the machine and for providing a roll angle output, and
- a processor, responsive to said pitch angle output and said roll angle output, said processor determining the orientation, r , of the pitch axis of the machine according to a selected one of the following:

$$r = \sin^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \cos^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \tan^{-1} [\text{Pitch}/\text{Roll}].$$

5. The system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim 4, in which said processor selects among the formulae for determining the orientation, r , in dependence upon which formula is likely to provide the most accurate indication of orientation.

6. The system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim 4, in which said first and second inclinometers comprise a single, dual axis inclinometer.

7. The system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim 4, in which said processor selects

among the formulae for determining the orientation, r , in dependence upon which quadrant the longitudinal direction of the machine is found.

8. The system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim 7, in which said processor selects a cosine formula when the orientation of the machine is near $\pm 90^\circ$, and in which said processor selects a sine formula when the orientation of the machine is near 0° or near 180° .

9. A method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising the steps of:

- determining the pitch angle, Pitch, of the machine and providing a pitch angle output,
- determining the roll angle, Roll, of the machine and for providing a roll angle output, and
- determining the orientation, r , of the pitch axis of the machine according to the relationship:

$$r = \sin^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}].$$

10. A method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising the steps of:

- determining the pitch angle, Pitch, of the machine and providing a pitch angle output,
- determining the roll angle, Roll, of the machine and for providing a roll angle output, and
- determining the orientation, r , of the pitch axis of the machine according to the relationship:

$$r = \tan^{-1} [\text{Pitch}/\text{Roll}].$$

11. A method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising the steps of:

- determining the pitch angle, Pitch, of the machine and providing a pitch angle output,
- determining the roll angle, Roll, of the machine and for providing a roll angle output, and
- determining the orientation, r , of the pitch axis of the machine according to the relationship:

$$r = \cos^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}].$$

12. A method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising the steps of:

- determining the pitch angle, Pitch, of the machine and providing a pitch angle output,
- determining the roll angle, Roll, of the machine and providing a roll angle output, and
- determining the orientation, r , of the pitch axis of the machine according to a selected one of the relationships:

$$r = \sin^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \cos^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \tan^{-1} [\text{Pitch}/\text{Roll}].$$

13. The method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim 12, in which the step of determining the orientation, r , according to a selected one of the relationships includes the step of selecting among the relationships in dependence upon which relationship is likely to provide the most accurate indication of orientation.

14. The method for determining the orientation, r , of a machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, according to claim 12, in which the steps of determining the pitch angle, Pitch, of the machine and providing a pitch angle output, determining the roll angle, Roll, of the machine and for providing a roll angle output, comprises the steps of measuring said Pitch angle and said Roll angle with first and second inclinometers, said inclinometers oriented to provide measured angles in the desired orientation.

15. The method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim 12, in which the steps of determining the pitch angle, Pitch, of the machine and providing a pitch angle output, determining the roll angle, Roll, of the machine and for providing a roll angle output, comprise the step of selecting among the formulae for determining the orientation, r , in dependence upon which quadrant the longitudinal direction of the machine is found.

16. The method for determining the orientation, r , of an excavating machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, in which a cosine formula when the orientation of the excavating machine is near $\pm 90^\circ$, and in which said processor selects a sine formula when the orientation of the excavating machine is near 0° or near 180° .

17. A system for determining the orientation, r , of an excavating machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising:

- a first inclinometer for determining the pitch angle, Pitch, of the excavating machine and providing a pitch angle output,
- a second inclinometer for determining the roll angle, Roll, of the excavating machine and for providing a roll angle output, and
- a processor, responsive to said pitch angle output and said roll angle output, said processor determining the orientation, r , using the said pitch and roll output.

18. The system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim 17, in which said first and second inclinometers comprise a single, dual axis inclinometer.

19. A system for determining the orientation, r , of an excavating machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising:

- a first inclinometer for determining the pitch angle, Pitch, of the excavating machine and providing a pitch angle output,

a second inclinometer for determining the roll angle, Roll, of the excavating machine and for providing a roll angle output, and

a processor, responsive to said pitch angle output and said roll angle output, said processor determining the orientation, r , of the roll axis of the excavating machine according to the following:

$$r = \sin^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}].$$

20. A system for determining the orientation, r , of an excavating machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising:

a first inclinometer for determining the pitch angle, Pitch, of the excavating machine and providing a pitch angle output,

a second inclinometer for determining the roll angle, Roll, of the excavating machine and for providing a roll angle output, and

a processor, responsive to said pitch angle output and said roll angle output, said processor determining the orientation, r , of the roll axis of the excavating machine according to the following:

$$r = \cos^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}].$$

21. A system for determining the orientation, r , of an excavating machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising:

a first inclinometer for determining the pitch angle, Pitch, of the excavating machine and providing a pitch angle output,

a second inclinometer for determining the roll angle, Roll, of the excavating machine and for providing a roll angle output, and

a processor, responsive to said pitch angle output and said roll angle output, said processor determining the orientation, r , of the roll axis of the machine according to the following:

$$r = \tan^{-1} [\text{Roll}/\text{Pitch}].$$

22. A system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising:

a first inclinometer for determining the pitch angle, Pitch, of the machine and providing a pitch angle output,

a second inclinometer for determining the roll angle, Roll, of the machine and for providing a roll angle output, and

a processor, responsive to said pitch angle output and said roll angle output, said processor determining the orientation, r , of the roll axis of the machine according to a selected one of the following:

$$r = \sin^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \cos^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \tan^{-1} [\text{Roll}/\text{Pitch}].$$

23. The system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with

respect to the direction across the site in which there is no slope, according to claim **22**, in which said processor selects among the formulae for determining the orientation, r , in dependence upon which formula is likely to provide the most accurate indication of orientation.

24. The system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim **22**, in which said first and second inclinometers comprise a single, dual axis inclinometer.

25. The system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim **22**, in which said processor selects among the formulae for determining the orientation, r , in dependence upon which quadrant the longitudinal direction of the machine is found.

26. The system for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim **25**, in which said processor selects a cosine formula when the orientation of the machine is near $\pm 90^\circ$, and in which said processor selects a sine formula when the orientation of the machine is near 0° or near 180° .

27. A method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising the steps of:

determining the pitch angle, Pitch, of the machine and providing a pitch angle output,

determining the roll angle, Roll, of the machine and for providing a roll angle output, and

determining the orientation, r , of the roll axis of the machine according to the relationship:

$$r = \sin^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}].$$

28. A method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising the steps of:

determining the pitch angle, Pitch, of the machine and providing a pitch angle output,

determining the roll angle, Roll, of the machine and for providing a roll angle output, and

determining the orientation, r , of the roll axis of the machine according to the relationship:

$$r = \tan^{-1} [\text{Roll}/\text{Pitch}].$$

29. A method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising the steps of:

determining the pitch angle, Pitch, of the machine and providing a pitch angle output,

determining the roll angle, Roll, of the machine and for providing a roll angle output, and

determining the orientation, r , of the roll axis of the machine according to the relationship:

$$r = \cos^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}].$$

30. A method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with

respect to the direction across the site in which there is no slope, which is perpendicular to the direction of the fall line of the sloped portion, comprising the steps of:

determining the pitch angle, Pitch, of the machine and providing a pitch angle output,
determining the roll angle, Roll, of the machine and providing a roll angle output, and
determining the orientation, r , of the roll axis of the machine according to a selected one of the relationships:

$$r = \sin^{-1} [\text{Roll}/(\text{Pitch}^2 + \text{Roll})^{1/2}], \text{ or}$$

$$r = \cos^{-1} [\text{Pitch}/(\text{Pitch}^2 + \text{Roll}^2)^{1/2}], \text{ or}$$

$$r = \tan^{-1} [\text{Roll}/\text{Pitch}].$$

31. The method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim **30**, in which the step of determining the orientation, r , according to a selected one of the relationships includes the step of selecting among the relationships in dependence upon which relationship is likely to provide the most accurate indication of orientation;

32. The method for determining the orientation, r , of a machine sitting on a sloped portion of a construction site with respect to the direction across the site in which there is no slope, according to claim **30**, in which the steps of determining the pitch angle, Pitch, of the machine and providing a pitch angle output, determining the roll angle, Roll, of the machine and for providing a roll angle output, comprises the steps of measuring said Pitch angle and said Roll angle with first and second inclinometers, said inclinometers oriented to provide measured angles in the desired orientation.

33. The method for determining the orientation, r , of a machine sitting on a sloped portion of a work site with respect to the direction across the site in which there is no slope, according to claim **30**, in which the steps of determining the pitch angle, Pitch, of the machine and providing a pitch angle output, determining the roll angle, Roll, of the machine and for providing a roll angle output, comprise the step of selecting among the formulae for determining the orientation, r , in dependence upon which quadrant the longitudinal direction of the machine is found.

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