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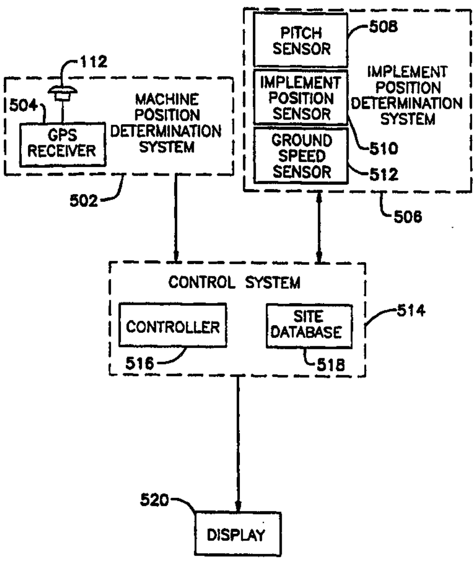
(54) Title: METHOD AND APPARATUS FOR MONITORING AND CONTROLLING AN EARTHWORKING IMPLEMENT AS IT APPROACHES A DESIRED DEPTH OF CUT

(57) Abstract

A method and apparatus (100) for determining the location of an earthworking implement (104) with respect to a desired depth of cut (106) between a layer of material to remove (108) and a layer of material to remain (110). As the earthworking implement (104) approaches or moves lower than the desired depth of cut (106), a control system (514) responsively stops movement of the implement (104) toward the desired depth of cut (106) or lifts the implement (104) from the material to remain (110).



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Description

Method and Apparatus for Monitoring and Controlling an Earthworking Implement as it Approaches a Desired Depth of Cut

Technical Field

This invention relates generally to a method and apparatus for monitoring and controlling an earthworking implement and, more particularly, to a method and apparatus for monitoring and controlling an earthworking implement as it approaches a desired depth of cut between two regions of material.

Background Art

Earthworking machines, e.g., track-type tractors, are used quite often to remove a layer of a first material to expose an underlying layer of a second material. For example, it may be desired to expose a layer of coal or other ore which may be located under a layer of soil and rock. The layer of soil is commonly known as overburden, and needs to be removed to mine the ore. As another example, it may be desired to remove material to a desired level to prepare a work site for further construction, such as a road or parking lot.

Methods have been employed to increase the efficiency of the material removal process. For example, in U.S. Patent No. 5,560,431, to Stratton, the Patent discloses a control system which monitors the blade force and ground speed of an earthworking machine and responsively controls the depth of cut of the blade to optimize the efficiency of the earthworking operation. If the system determines that the blade is capable of pushing more material, the blade is lowered further into the ground.

However, the control system developed by the Stratton Patent does not differentiate between the material desired to be removed and the material desired to be exposed. The control system may determine that the blade can be lowered to push more material, with the result that some material which is desired to remain intact may be removed in the process.

In addition, the terrain covered by an earthworking machine is usually uneven. As the machine traverses the terrain, the machine will follow the contours of the ground, causing the blade to periodically cut lower than the desired depth of cut and remove part of the material that should not be removed.

The present invention is directed to overcoming one or more of the problems as set forth above.

Disclosure of the Invention

In one aspect of the present invention a method for monitoring and controlling an earthworking implement with respect to a desired depth of cut is disclosed. The method includes the steps of monitoring the position and movement of the implement, stopping the movement of the implement toward the desired depth of cut in response to the implement nearing the desired depth of cut, and lifting the implement in response to the implement moving lower than the desired depth of cut.

In another aspect of the present invention an apparatus for monitoring and controlling an earthworking implement with respect to a desired depth of cut is disclosed. The apparatus includes a control system, a machine position determination system, an implement position determination system, and a site database including data determining the location of the desired depth of cut. The apparatus also includes a controller in the control system which receives a machine position signal, an implement position signal, and the site data, and responsively determines the position of the implement with respect to the desired depth of cut.

Brief Description of the Drawings

Fig. 1 is a diagrammatic illustration of an earthworking machine as embodied in the present invention;

Fig. 2 is a diagrammatic illustration of an earthworking implement in one embodiment of the present invention;

Fig. 3 is a diagrammatic illustration of an earthworking implement in another embodiment of the present invention;

Fig. 4 is a diagrammatic illustration of an earthworking implement in yet another embodiment of the present invention;

Fig. 5 is a block diagram illustrating the apparatus of the present invention;

Fig. 6 is a flow diagram illustrating one aspect of the present invention; and

Fig. 7 is a flow diagram illustrating another aspect of the present invention.

Best Mode for Carrying Out the Invention

With reference to the drawings, and in

particular with reference to Fig. 1, an earthworking machine 102 as embodied in the present invention is shown. The earthworking machine 102 of Fig. 1 is shown as a track-type tractor. However, other types of earthworking machines, e.g., scrapers, motor graders, excavators, may be used in the present invention.

The earthworking machine 102 includes an earthworking implement 104, e.g., a bulldozer blade. The earthworking implement 104 is used to move material. For example, the earthworking implement 104 may remove a layer of material from a site. The type of material to remove may be a layer of overburden that is covering a layer of a second material, such as ore to be mined. It may also be desired to remove material to cause the site to conform to a desired depth and contour, e.g., for construction of a road or parking lot.

As specifically shown in Fig. 1, a layer of a material to remove 108 is located over a layer of a material to remain 110. The material to remove 108 may be overburden that covers a layer of ore to be mined. The boundary between the material to remove 108 and the material to remain 110 is known in the present invention as a desired depth of cut 106.

Referring now to Figs. 2-4, three embodiments of the operation of the present invention are shown. In Fig. 2, the earthworking implement 104 is shown removing a portion of the material to remove 108. Part of the material to remove 108 is not being removed, resulting in the material to remain 110 remaining unexposed. The condition shown in Fig. 2 will require at least one more pass of the earthworking machine 102 to remove the remaining portion of the material to remove 108. If the earthworking machine 102 is capable of removing all of the material to remove 108 in one pass, then the operation shown in Fig. 2 is considered inefficient since the additional passes performed add unnecessary costs and require additional time.

However, there are some situations where it is desired to remove material at a predetermined distance above the desired depth of cut 106. For example, a track-type tractor is generally considered to be a rough cut machine, i.e., it is difficult to remove material with a high degree of accuracy. When it is desired to remove material to remove 108 to the desired depth of cut 106 accurately, the track-type tractor may be used to remove material to remove 108 to a predetermined distance above the desired depth of cut 106. Then, a more precise earthworking machine, such as a motor grader or wheel loader may remove the remaining material to remove 108 to the desired depth of cut 106.

Referring to Fig. 3, a second embodiment of the operation of the present invention is shown. The earthworking implement 104 is removing the entire layer of the material to remove 108, and exposing the material to remain 110 without removing any of the material to remain 110. The desired depth of cut 106 is reached in one pass, thus optimizing the efficiency of the earthworking operation.

Referring to Fig. 4, a third embodiment of the operation of the present invention is shown. The earthworking implement 104 is removing the entire layer of the material to remove 108, and is removing a portion of the material to remain 110. In the situation of an ore mining operation, the condition shown in Fig. 4 results in wasteful removal of a material that is desired to be mined. Alternatively, if the desired depth of cut 106 is for construction of a site, removing too much material may require adding material back to the site to restore the desired depth of cut 106.

Referring now to Fig. 5, a block diagram of the present invention is shown.

A machine position determination system 502 is located on the earthworking machine 102. The machine position determination system 502 includes a GPS antenna 112 mounted on a fixed position on the earthworking machine 102, preferably above the operator's cab of the machine to maximize the satellite signal reception. A GPS receiver 504, mounted on the earthworking machine 102, receives the GPS satellite signals from the GPS antenna 112. The theory and operation of GPS positioning is well known in the art and will not be discussed further.

The machine position determination system 502 delivers a machine position signal to a control system 514 located on the earthworking machine 102. The control system 514 is discussed in more detail below.

The machine position determination system 502 is designed to determine the position coordinates of the point of location of the GPS antenna 112 on the earthworking machine 102. It is often desired to determine the position coordinates of a point on the earthworking implement 104, preferably a point on the cutting edge of the implement.

An implement position determination system 506 includes a pitch sensor 508 that senses the pitch of the earthworking machine 102, an implement position sensor 510 that determines the position of the earthworking implement 104, and a ground speed sensor 512 that senses the ground speed of the earthworking machine 102.

The implement position determination system 506 delivers an implement position signal to the control system 514.

The control system 514 includes a site database 518, which contains data describing features of the site. Data in the site database includes, but is not limited to, data determining the location of the desired depth of cut 106.

The control system 514 also includes a controller 516. Preferably, the controller 516 is a microprocessor. The controller 516 receives the machine position signal, the implement position signal, and the site data, and responsively determines the position of the earthworking implement 104 with respect to the desired depth of cut 106.

A display 520 receives data from the control system 514 and displays the position of the earthworking implement 104 with respect to the interface 106.

Referring now to Fig. 6, a flowchart illustrating a method for monitoring and controlling an earthworking implement 104 with respect to an interface 106 is shown.

In a first control block 602, the position and movement of the earthworking implement 104 is monitored with respect to the location of the desired depth of cut 106.

In a first decision block 604, it is determined if the earthworking implement 104 has moved lower than the desired depth of cut 106, as illustrated in Fig. 4, therefore causing the earthworking implement 104 to remove some of the material to remain 110. If it is determined that the earthworking implement 104 has moved lower than the desired depth of cut 106, then control proceeds to a second control block 606, where the earthworking implement 104 is lifted out of the material to remain 110. Otherwise, control proceeds to a second decision block 608.

In the second decision block 608, it is determined if the earthworking implement 104 is nearing the desired depth of cut 106. In the preferred embodiment, movement of the earthworking implement 104 below a predetermined threshold above the desired depth of cut 106 would result in the determination that the desired depth of cut 106 is being approached.

If it is determined that the earthworking implement 104 is nearing the desired depth of cut 106, then control proceeds to a third control block 610, where the movement of the earthworking implement 104 toward the desired depth of cut 106 is stopped. Otherwise, control returns to the first control block 602.

Referring now to Fig. 7, a flowchart illustrating a method for determining the position of the earthworking implement 104 with respect to the interface 106 is shown.

In a first control block 702, the location of the desired depth of cut 106 is determined with respect to the earthworking machine 102. In the preferred embodiment, the geographical coordinates of the GPS antenna 112 mounted on the earthworking machine 102 are determined using, for example, an x,y,z coordinate system, where x,y,z refers to latitude, longitude, and altitude, respectively. The geographical location of the desired depth of cut 106 at the GPS antenna x and y coordinates is then looked up in the site database 518.

In a second control block 704, the position of the earthworking implement 104 with respect to the earthworking machine 102 is determined.

Control then proceeds to a third control block 706, where the position of the earthworking implement 104 is calculated with respect to the desired depth of cut 106. This is easily accomplished since the position of the earthworking implement 104 and the location of the desired depth of cut 106 have both been determined with respect to the earthworking machine 102. Therefore, the position of the earthworking machine, i.e., the geographical coordinates of the GPS antenna 112 mounted on the earthworking machine 102, is a common point of reference linking the locations of the earthworking implement 104 and the desired depth of cut 106 together.

In a fourth control block 708, the position of the earthworking implement 104 relative to the desired depth of cut 106 is displayed to an operator. Preferably, the display 520 is graphical. In one embodiment, the display 520 is located on the earthworking machine 102. In another embodiment, the display 520 is located at a remote site. In yet another embodiment, the earthworking machine 102 operates autonomously, and the display 520 is not used.

Industrial Applicability

As an example of the operation of the present invention, an earthworking machine 102, e.g., a track-type tractor, is used to remove layers of overburden from a work site where it is desired to expose a layer of ore. Due to uneven terrain and to control systems on the earthworking machine 102 designed to optimize the amount of material removed, some of the ore is frequently removed with the overburden. This results in valuable ore being wasted in the process.

The present invention is designed to monitor the position of the earthworking implement 104, e.g., a bulldozer blade, with respect to the ore interface 106, and prevent the earthworking implement 104 from removing ore during the overburden removal process. This may result in the need for the present invention to override any other blade optimization control systems. For example, if it is determined that the earthworking implement 104 has moved lower than the desired depth of cut 106, then the controller in the present invention overrides any command to position the blade at the current depth, and the blade is raised to the desired depth of cut 106.

As another example of the present invention, an earthworking machine 102, e.g., a track-type tractor, is used to remove material at a site to achieve a desired level and grade. For example, the design for a parking lot may require a predetermined slope to allow rain to flow to a drain. If the earthworking machine 102 removes too much material, then material must be added back to the site. This adds unwanted time and costs to the operation. The system of the present invention monitors the position of the earthworking implement 104 with respect to the desired depth of cut 106, and prevents the depth of cut of the earthworking implement 104 from moving lower than the desired depth of cut 106.

Other aspects, objects, and features of the present invention can be obtained from a study of the drawings, the disclosure, and the appended claims.

Claims

1. A method for monitoring and controlling an earthworking implement (104) with respect to a desired depth of cut (106), the earthworking implement (104) being controllably connected to an earthworking machine (102), the desired depth of cut (106) defining a boundary between a region of a material to remove (108) and a region of a material to remain (110), including the steps of:

monitoring the position and movement of said implement (104);

stopping the movement of said implement (104) toward said desired depth of cut (106) in response to said implement (104) nearing said desired depth of cut (106); and

lifting said implement (104) from said material to remain (110) in response to said implement (104) moving lower than said desired depth of cut (106).

2. A method, as set forth in claim 1, including the steps of:

determining the location of said desired depth of cut (106) with respect to said earthworking machine (102);

determining the position of said earthworking implement (104) with respect to said earthworking machine (102); and

calculating the position of said earthworking implement (104) with respect to said desired depth of cut (106).

3. A method, as set forth in claim 1, including the step of defining a predetermined distance above said desired depth of cut (106) as a new desired depth of cut.

4. A method, as set forth in claim 2, including the step of displaying the position of said earthworking implement (104) with respect to said desired depth of cut (106).

5. An apparatus (100) for monitoring and controlling an earthworking implement (104) with respect to a desired depth of cut (106), the earthworking implement (104) being controllably connected to an earthworking machine (102), the desired depth of cut (106) defining a boundary between a region of a material to remove (108) and a region of a material to remain (110), comprising:

a control system (514) connected to said earthworking machine (102);

a machine position determination system (502) connected to said earthworking machine (102), and adapted to deliver a machine position signal to said control system (514);

an implement position determination system (506) connected to said earthworking machine (102), and adapted to deliver an implement position signal (510) to said control system (514);

a site database (518) connected to said control system (514), said site database (518) including data that determines the location of said desired depth of cut (106); and

a controller (516) integrated with said control system (514) and adapted to receive said machine position signal, said implement position signal, and said site data, and responsively determine the position of said earthworking implement (104) with respect to said desired depth of cut (106).

6. An apparatus (100), as set forth in claim 5, wherein said machine position determination system (502) includes:

a GPS antenna (112) located at a fixed position on said earthworking machine (102); and

a GPS receiver (504) connected to said GPS antenna (112).

7. An apparatus (100), as set forth in claim 5, wherein said implement position determination system (506) includes:

a pitch sensor (508) mounted on said earthworking machine (102);

a ground speed sensor (512) mounted on said earthworking machine (102); and

an implement position sensor (510) mounted on said earthworking machine (102) and coupled to said earthworking implement (104).

8. An apparatus (100), as set forth in claim 5, wherein said material to remove (108) is overburden and said material to remain (110) is ore.

9. An apparatus (100), as set forth in claim 5, wherein said desired depth of cut (106) defines a desired level and contour.

10. An apparatus (100), as set forth in claim 5, including a new desired depth of cut (106) located a predetermined distance above said desired depth of cut (106).

11. An apparatus (100), as set forth in claim 5, including a display (520) located on said earthworking machine (102) adapted to display the position of said earthworking implement (104) with respect to said desired depth of cut (106).

12. An apparatus (100), as set forth in claim 11, wherein said display (520) is located on said earthworking machine (102).

13. An apparatus (100), as set forth in claim 11, wherein said display (520) is located at a site remote from said earthworking machine (102).

14. An apparatus (100) for monitoring and controlling an earthworking implement (104) with respect to a desired depth of cut (106), the earthworking implement (104) being controllably connected to an earthworking machine (102), the desired depth of cut (106) defining a boundary between a region of a material to remove (108) and a region of a material to remain (110), comprising:

a control system (514) connected to said earthworking machine (102);

a machine position determination system (502) connected to said earthworking machine (102), and adapted to deliver a machine position signal to said control system (514), said machine position determination system (502) including;

a GPS antenna (112) located at a fixed position on said earthworking machine (102); and

a GPS receiver (504) connected to said GPS antenna (112);

an implement position determination system (506) connected to said earthworking machine (102), and adapted to deliver an implement position signal to said control system (514), said implement position determination system (502) including;

a pitch sensor (508) mounted on said earthworking machine (102);

a ground speed sensor (512) mounted on said earthworking machine (102); and

an implement position sensor (510) mounted on said earthworking machine (102) and coupled to said earthworking implement (104);

a site database (518) connected to said control system (514), said site database (518) including data determining the location of said desired depth of cut (106); and

a controller (516) integrated with said control system (514) and adapted to receive said machine position signal, said implement position signal, and said site data, and responsively determine the position of said earthworking implement (104) with respect to said desired depth of cut (106).

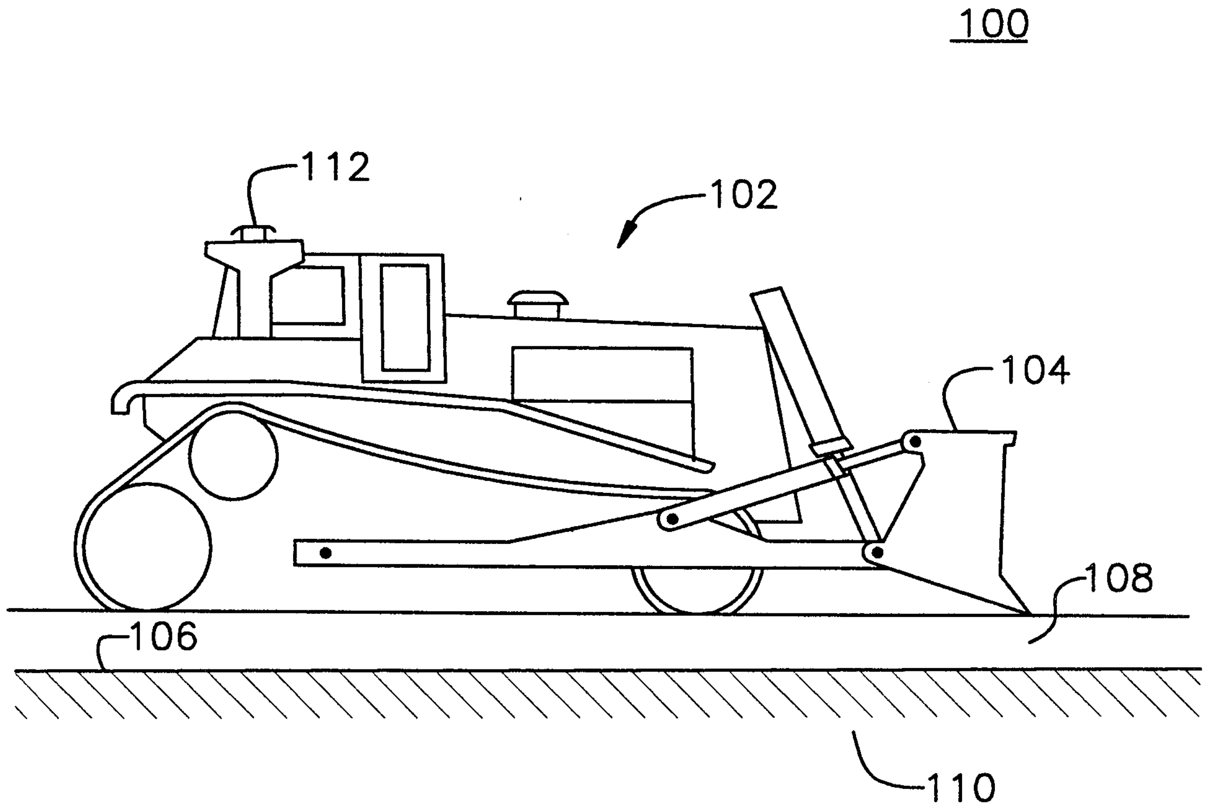


FIG. 1

FIG. 2

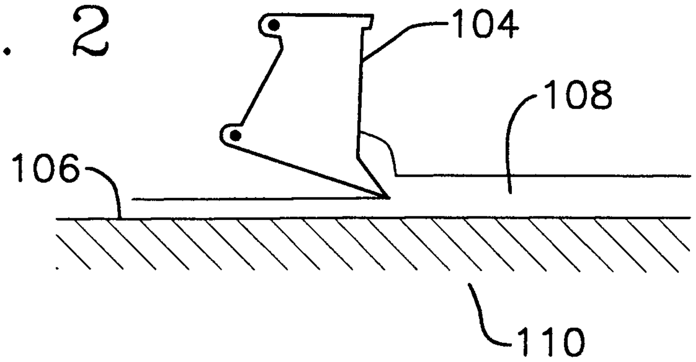


FIG. 3

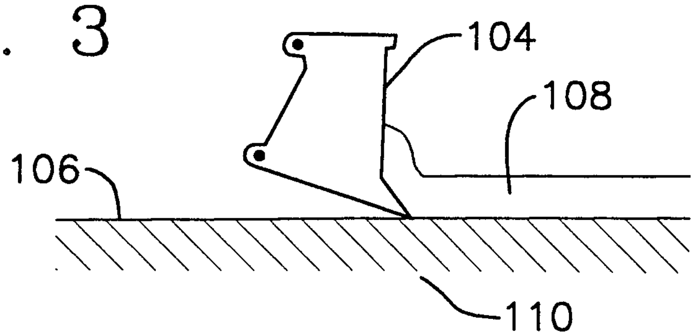
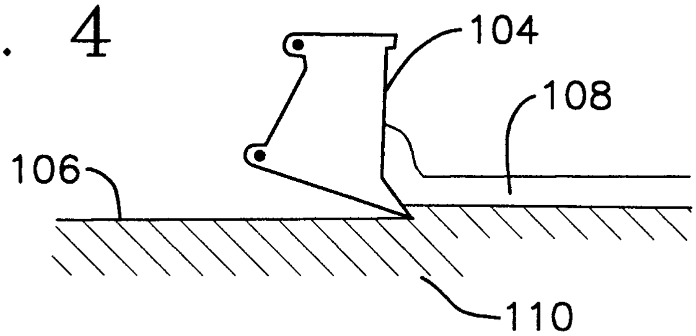
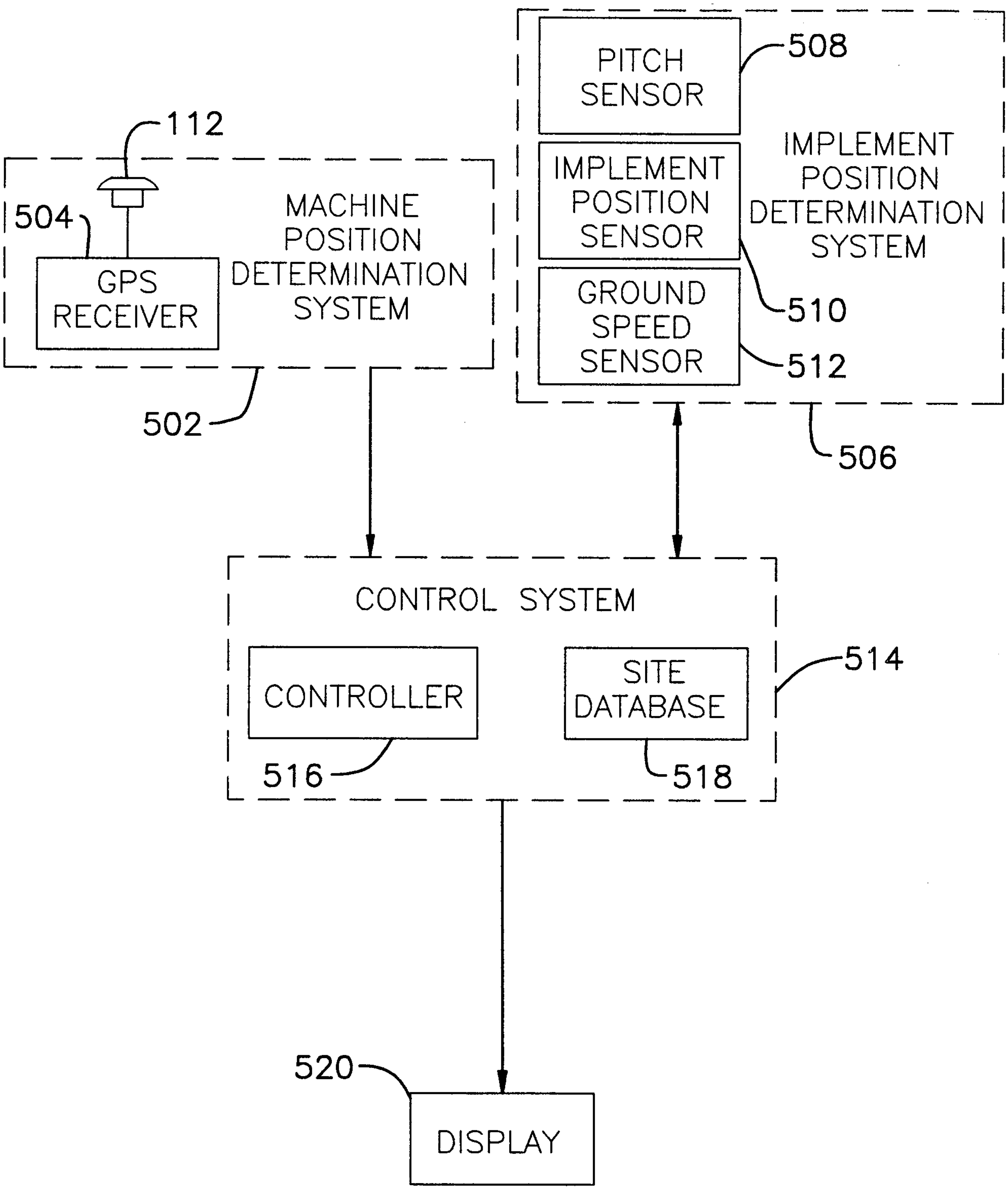


FIG. 4

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504
GPS RECEIVER
MACHINE POSITION DETERMINATION SYSTEM
502
PITCH SENSOR
508
IMPLEMENT POSITION SENSOR
510
GROUND SPEED SENSOR
512
IMPLEMENT POSITION DETERMINATION SYSTEM
506
CONTROL SYSTEM
CONTROLLER
516
SITE DATABASE
518
514
520
DISPLAY

FIG. 5

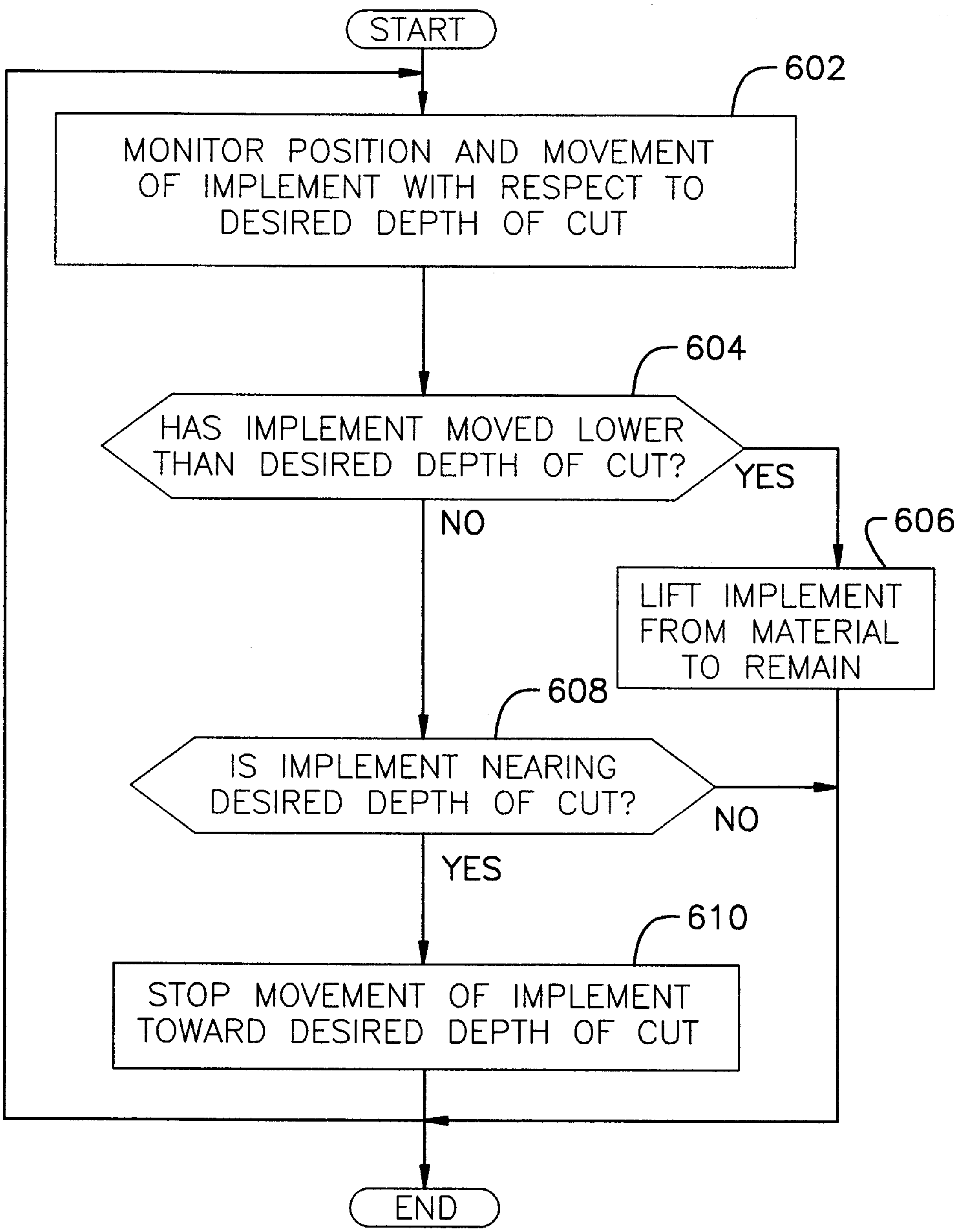
START
602
MONITOR POSITION AND MOVEMENT OF IMPLEMENT WITH RESPECT TO DESIRED DEPTH OF CUT
604
HAS IMPLEMENT MOVED LOWER THAN DESIRED DEPTH OF CUT?
YES
NO
606
LIFT IMPLEMENT FROM MATERIAL TO REMAIN
608
IS IMPLEMENT NEARING DESIRED DEPTH OF CUT?
NO
YES
610
STOP MOVEMENT OF IMPLEMENT TOWARD DESIRED DEPTH OF CUT
END

FIG. 6

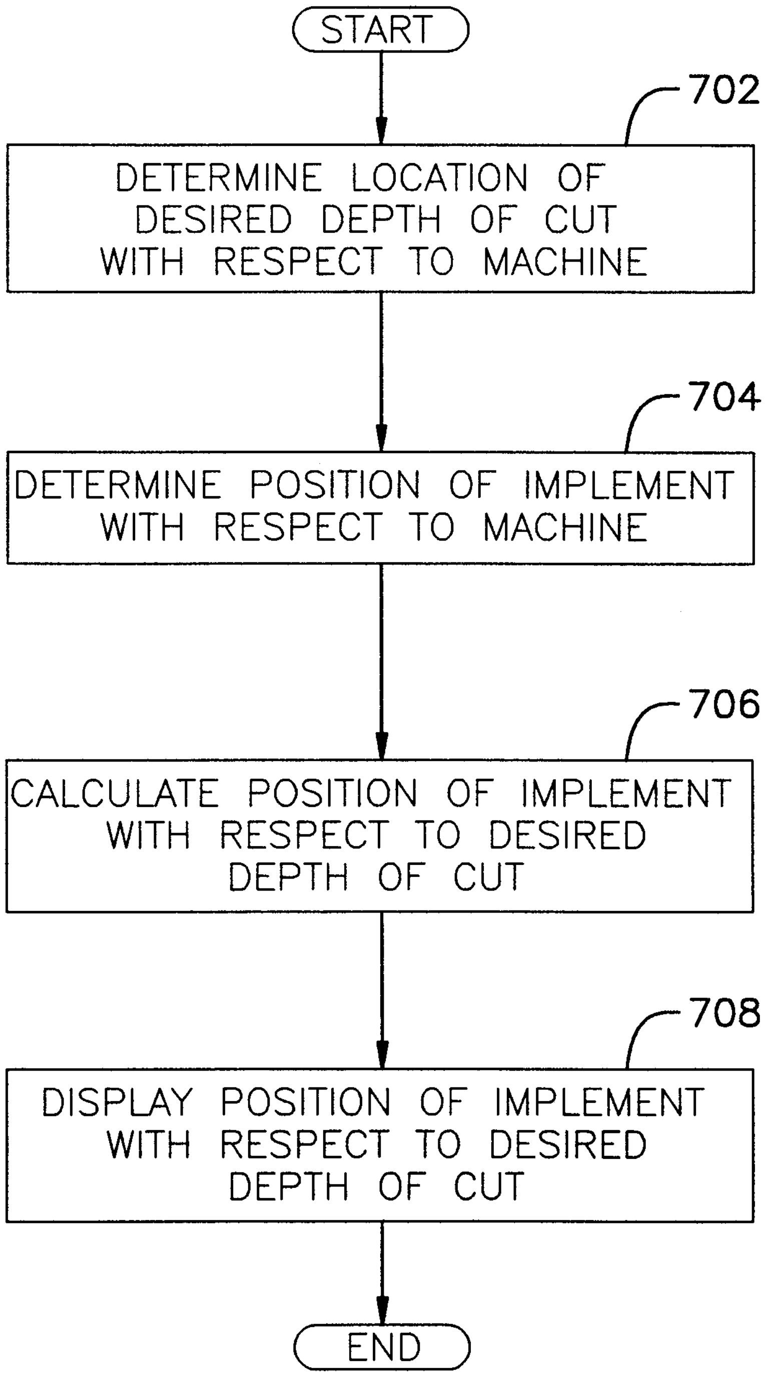
START
702
DETERMINE LOCATION OF DESIRED DEPTH OF CUT WITH RESPECT TO MACHINE
704
DETERMINE POSITION OF IMPLEMENT WITH RESPECT TO MACHINE
706
CALCULATE POSITION OF IMPLEMENT WITH RESPECT TO DESIRED DEPTH OF CUT
708
DISPLAY POSITION OF IMPLEMENT WITH RESPECT TO DESIRED DEPTH OF CUT
END

FIG. 7

INTERNATIONAL SEARCH REPORT

Interr   al Application No
PCT/US 98/11888

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   E02F3/84   E02F3/43

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   E02F

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 375 663 A (TEACH TED L) 27 December 1994 see abstract; figures 2-4 see column 5, line 14 - column 6, line 51 ---	1,2,5,6, 9,14
A	WO 97 01105 A (CATERPILLAR INC) 9 January 1997 see claims; figures ---	1,2,4-7, 9,11,14
A	EP 0 443 026 A (KOMATSU MFG CO LTD) 28 August 1991 see figures ---	1,5, 11-13
A	US 4 818 107 A (ONO TOYOICHI ET AL) 4 April 1989 see the whole document --- -/--	5,6,9, 11-14

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
2 October 1998	12/10/1998

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Intern   al Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 228 507 A (JOHN KELLY) 29 August 1990 see abstract; figures see page 5, line 23 - page 7, line 25 ---	1,5,11
A	US 4 157 118 A (FUKUMURA TOHRU ET AL) 5 June 1979 see abstract; figures ---	5
A	DE 195 10 376 A (CATERPILLAR INC) 28 September 1995 see figures ---	1
A	US 5 560 431 A (STRATTON KENNETH L) 1 October 1996 cited in the application see figures 2-4B see column 3, line 32 - line 38 ---	1,5,7
A	US 4 888 890 A (STUDEBAKER ROBERT H ET AL) 26 December 1989 see figures -----	1,5

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Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 98/11888

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 5375663	A	27-12-1994	NONE			
WO 9701105	A	09-01-1997	US	5612864	A	18-03-1997
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