US012392112B2

(12) United States Patent
Ito et al.

(10) Patent No.: US 12,392,112 B2
(45) Date of Patent: Aug. 19, 2025

(54) **WORK MACHINE STATE MONITORING SYSTEM AND WORK MACHINE STATE MONITORING METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 291 days.

(21) Appl. No.: **18/007,818**

(22) PCT Filed: **May 20, 2021**

(86) PCT No.: **PCT/JP2021/019270**

§ 371 (c)(1),
(2) Date: **Dec. 2, 2022**

(87) PCT Pub. No.: **WO2021/246190**

PCT Pub. Date: **Dec. 9, 2021**

(65) **Prior Publication Data**

US 2023/0228064 A1 Jul. 20, 2023

(30) **Foreign Application Priority Data**

Jun. 4, 2020 (JP) 2020-097595

(51) **Int. Cl.**
E02F 9/26 (2006.01)
E02F 3/32 (2006.01)

(52) **U.S. Cl.**
CPC . ***E02F 9/26*** (2013.01); *E02F 3/32* (2013.01)

(58) **Field of Classification Search**
CPC E02F 9/26; E02F 3/32
See application file for complete search history.

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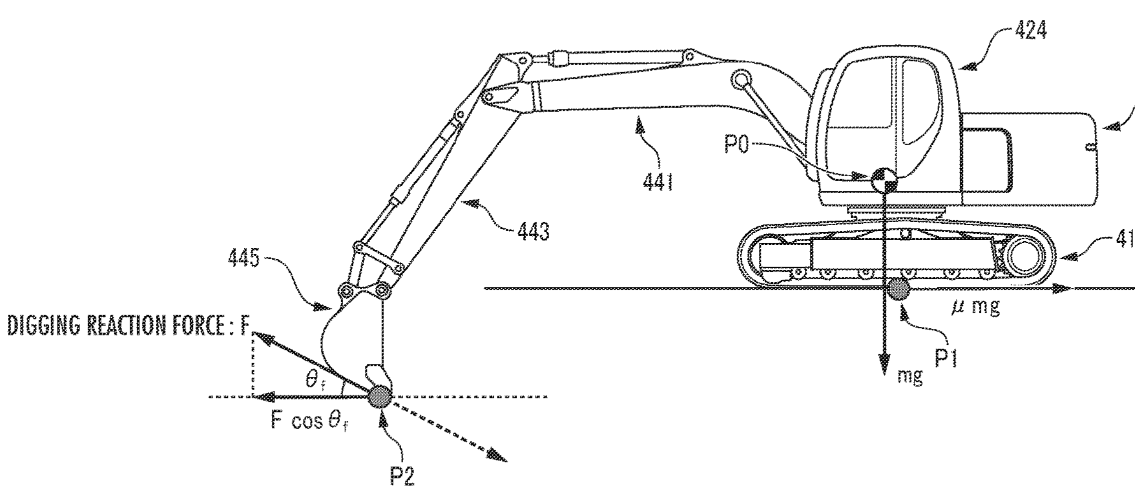
(57) **ABSTRACT**

A system capable of improving accuracy of information relating to the degree of instability of a work machine such as an excavator, the information being provided to an operator of the work machine. Instability degree information, which indicates instability degrees Is**1**, Is**2** of a base body (lower traveling body **410** and upper turning body **420**) for which instability values have been assessed as continuous variables, is output to a remote image output device **221** (information output device) such that the form of the output varies continuously depending on continuous changes in the instability degrees Is**1**, Is**2**. An operator of a work machine **40** can highly accurately recognize the closeness of the current instability degree of the base body to a threshold

(Continued)



value at which the base body becomes unstable, and consequently a tolerable range in which the work mechanism, etc. are operated while avoiding instability of the base body.

8 Claims, 13 Drawing Sheets

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FIG. 1

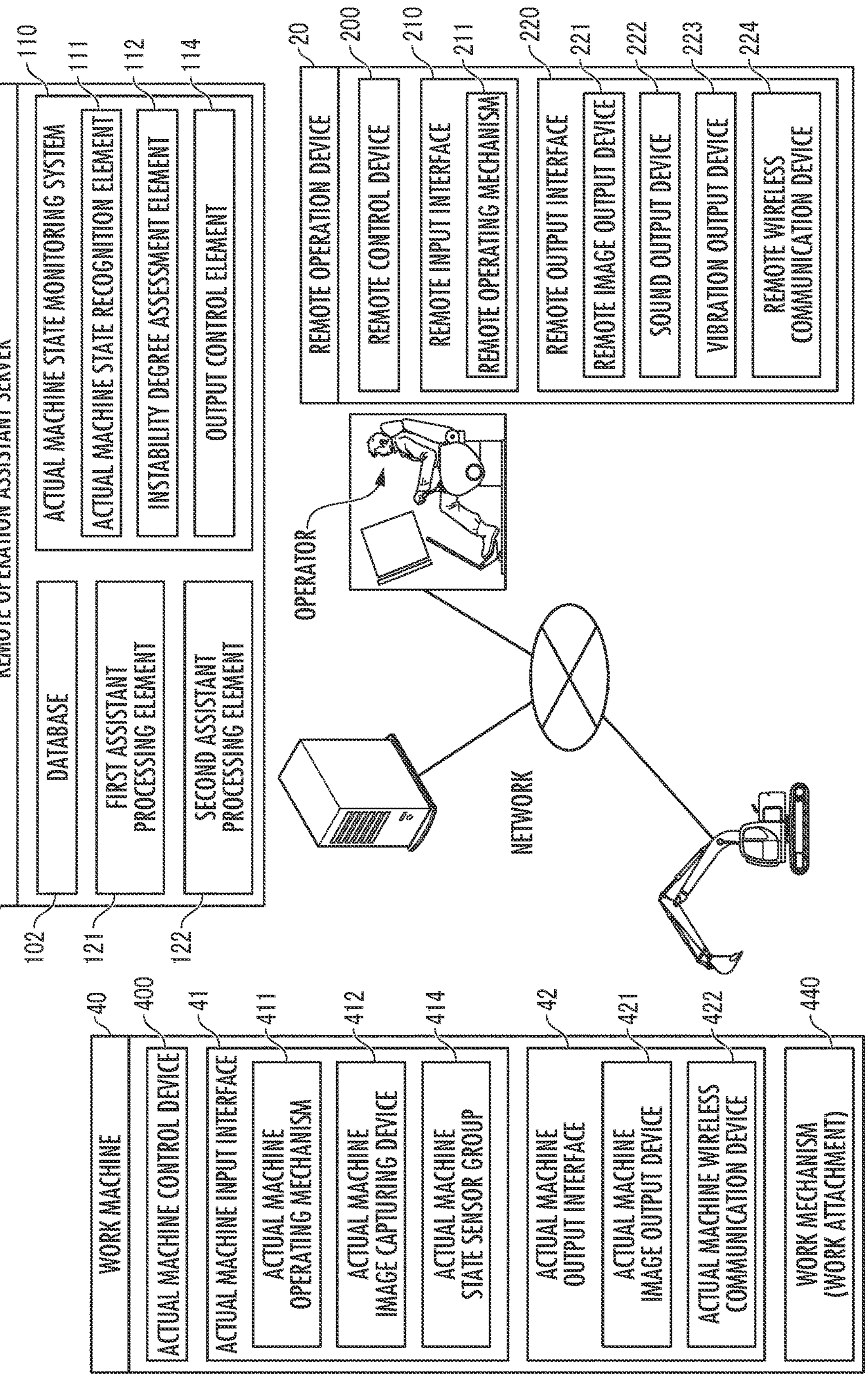

REMOTE OPERATION ASSISTANT SERVER
DATABASE
FIRST ASSISTANT PROCESSING ELEMENT
SECOND ASSISTANT PROCESSING ELEMENT
ACTUAL MACHINE STATE MONITORING SYSTEM
ACTUAL MACHINE STATE RECOGNITION ELEMENT
INSTABILITY DEGREE ASSESSMENT ELEMENT
OUTPUT CONTROL ELEMENT
10
102
121
122
110
111
112
114
REMOTE OPERATION DEVICE
REMOTE CONTROL DEVICE
REMOTE INPUT INTERFACE
REMOTE OPERATING MECHANISM
REMOTE OUTPUT INTERFACE
REMOTE IMAGE OUTPUT DEVICE
SOUND OUTPUT DEVICE
VIBRATION OUTPUT DEVICE
REMOTE WIRELESS COMMUNICATION DEVICE
20
200
210
211
220
221
222
223
224
OPERATOR
NETWORK
WORK MACHINE
ACTUAL MACHINE CONTROL DEVICE
ACTUAL MACHINE INPUT INTERFACE
ACTUAL MACHINE OPERATING MECHANISM
ACTUAL MACHINE IMAGE CAPTURING DEVICE
ACTUAL MACHINE STATE SENSOR GROUP
ACTUAL MACHINE OUTPUT INTERFACE
ACTUAL MACHINE IMAGE OUTPUT DEVICE
ACTUAL MACHINE WIRELESS COMMUNICATION DEVICE
WORK MECHANISM (WORK ATTACHMENT)
40
400
41
411
412
414
42
421
422
440

FIG.2

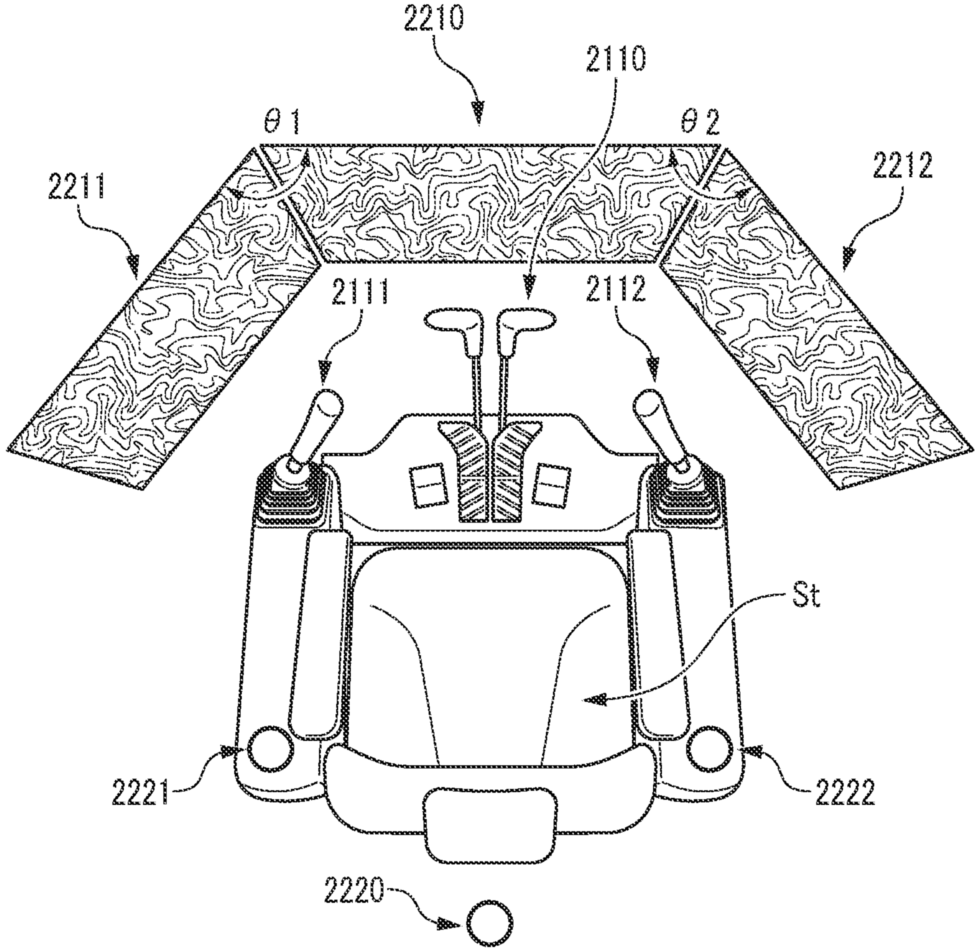


FIG.3

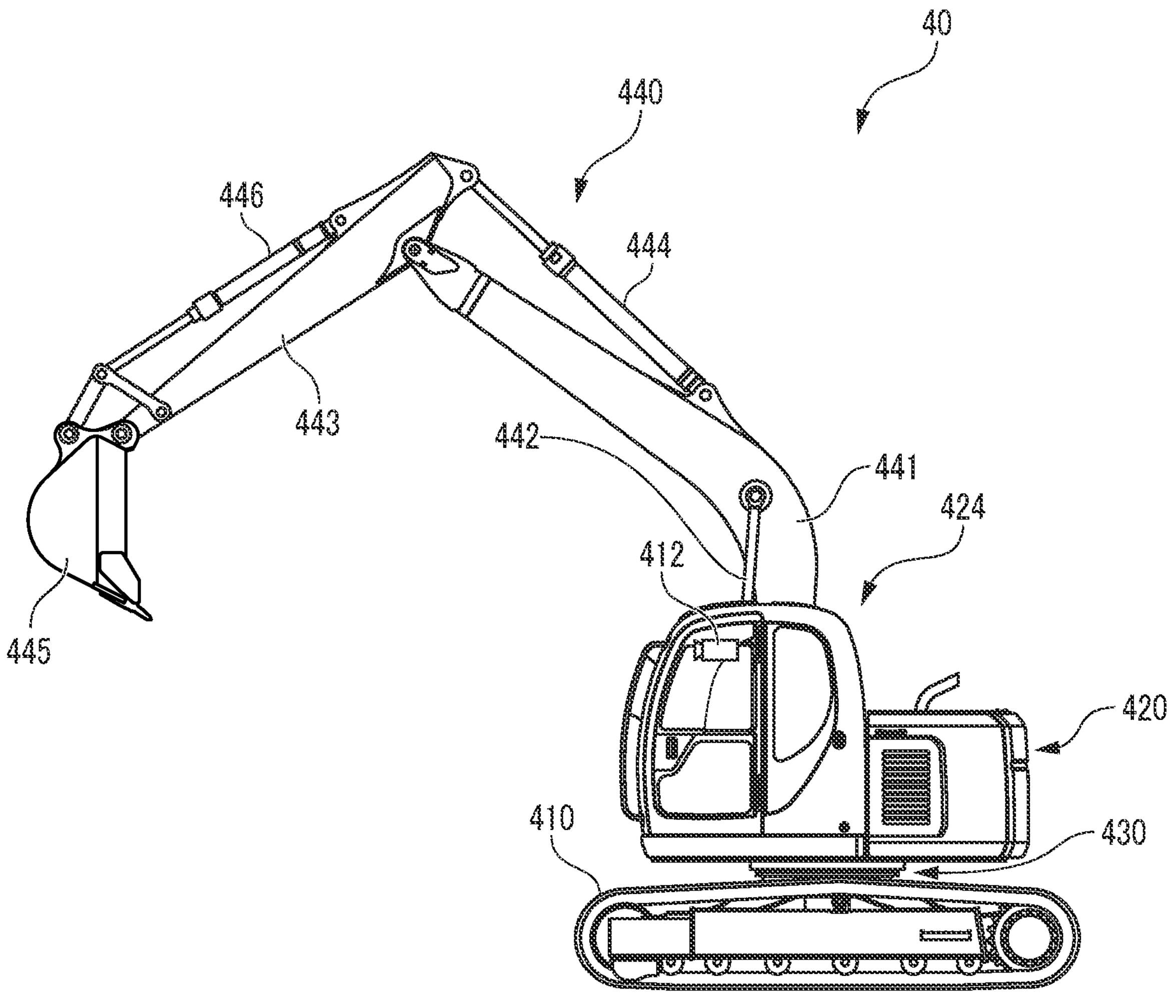


FIG.4

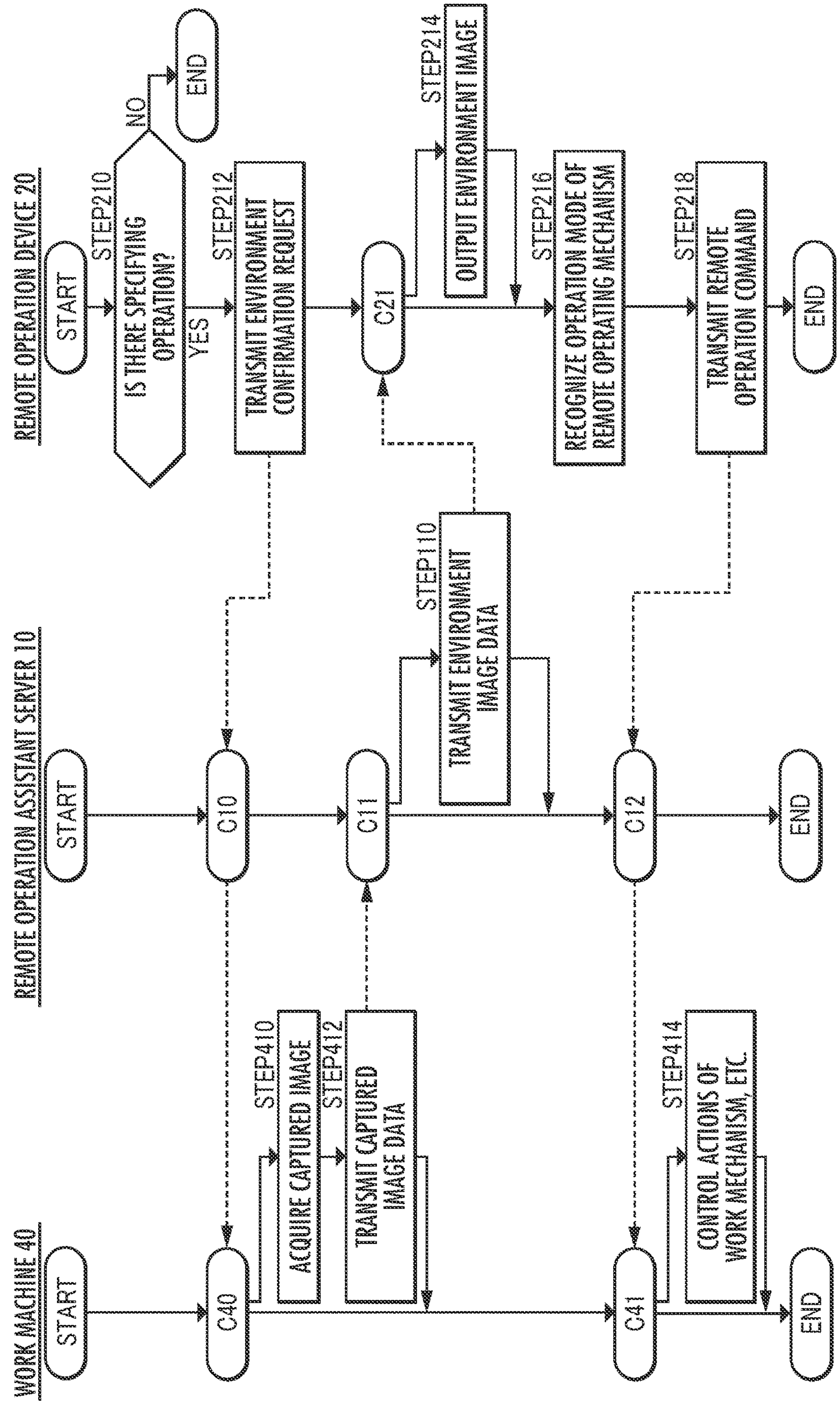
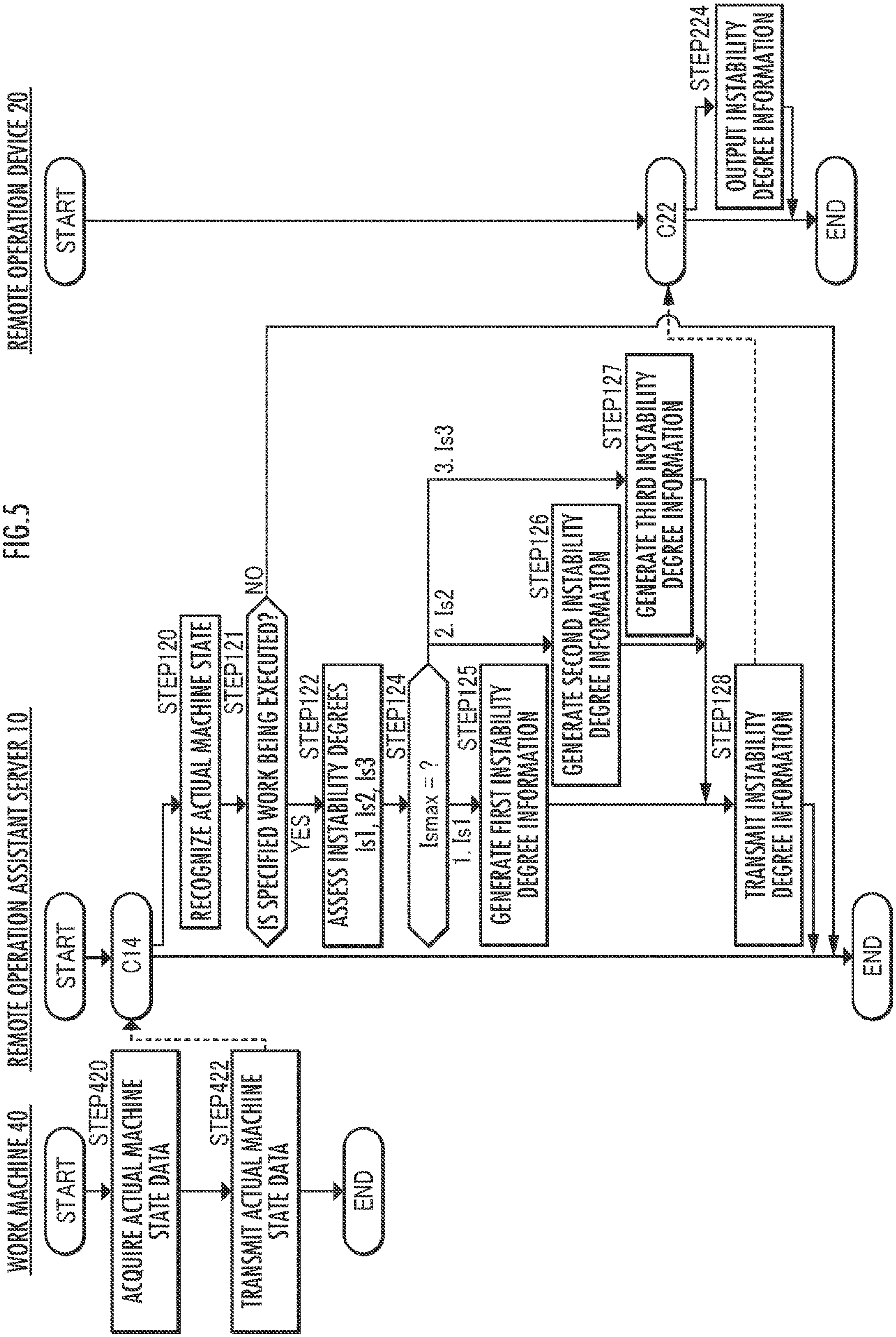

REMOTE OPERATION DEVICE 20
START
STEP210
IS THERE SPECIFYING OPERATION?
NO
END
YES
STEP212
TRANSMIT ENVIRONMENT CONFIRMATION REQUEST
C21
STEP214
OUTPUT ENVIRONMENT IMAGE
STEP216
RECOGNIZE OPERATION MODE OF REMOTE OPERATING MECHANISM
STEP218
TRANSMIT REMOTE OPERATION COMMAND
END
REMOTE OPERATION ASSISTANT SERVER 10
START
C10
C11
STEP110
TRANSMIT ENVIRONMENT IMAGE DATA
C12
END
WORK MACHINE 40
START
C40
STEP410
ACQUIRE CAPTURED IMAGE
STEP412
TRANSMIT CAPTURED IMAGE DATA
C41
STEP414
CONTROL ACTIONS OF WORK MECHANISM, ETC.
END

FIG.5



WORK MACHINE 40
START
STEP420
ACQUIRE ACTUAL MACHINE STATE DATA
STEP422
TRANSMIT ACTUAL MACHINE STATE DATA
END
REMOTE OPERATION ASSISTANT SERVER 10
START
C14
STEP120
RECOGNIZE ACTUAL MACHINE STATE
STEP121
IS SPECIFIED WORK BEING EXECUTED?
YES
NO
STEP122
ASSESS INSTABILITY DEGREES Is1, Is2, Is3
STEP124
Ismax = ?
1. Is1
2. Is2
3. Is3
STEP125
GENERATE FIRST INSTABILITY DEGREE INFORMATION
STEP126
GENERATE SECOND INSTABILITY DEGREE INFORMATION
STEP127
GENERATE THIRD INSTABILITY DEGREE INFORMATION
STEP128
TRANSMIT INSTABILITY DEGREE INFORMATION
END
REMOTE OPERATION DEVICE 20
START
C22
STEP224
OUTPUT INSTABILITY DEGREE INFORMATION
END

FIG.6

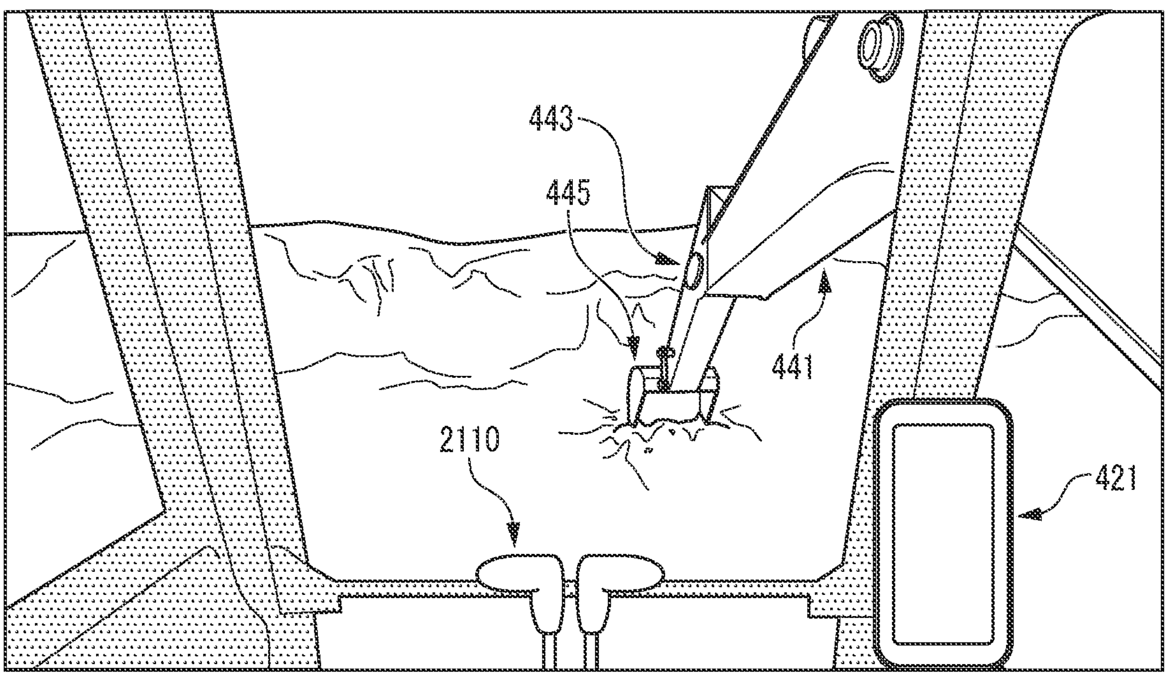


FIG.7

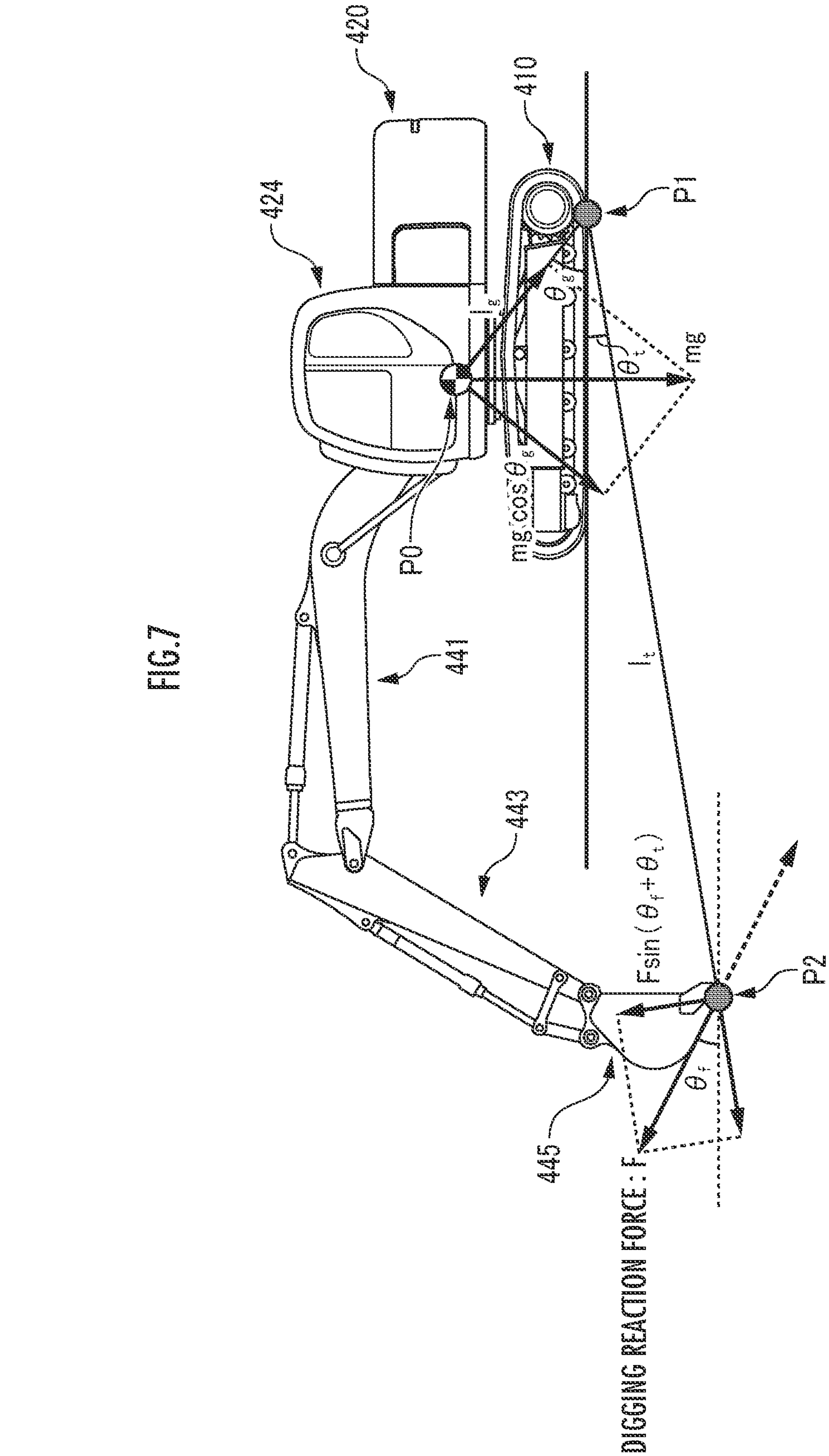
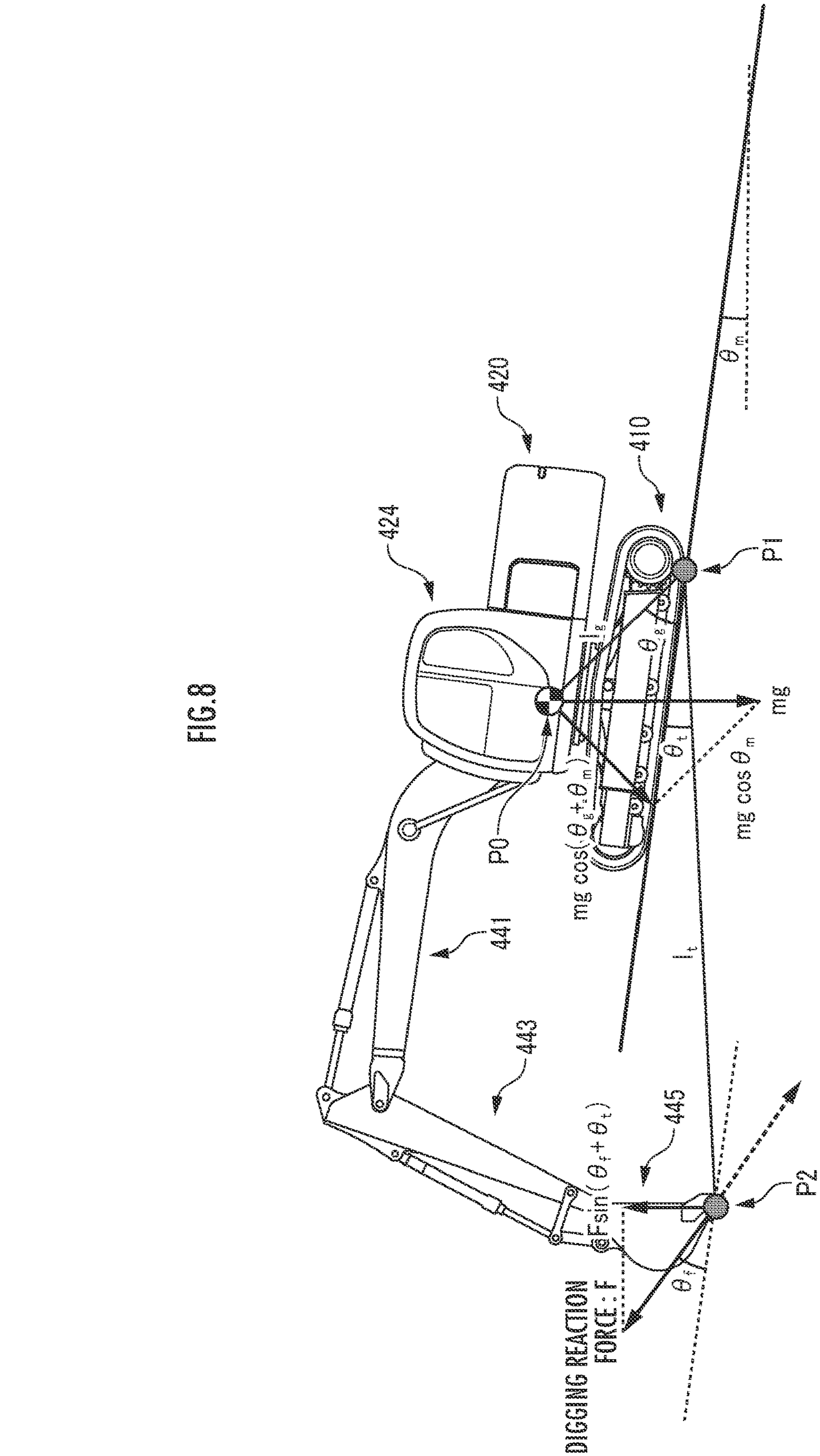

420
410
424
P1
l_g
θ_g
θ_t
mg
mg cos θ_g
P0
441
l_t
443
Fsin($\theta_f+\theta_t$)
P2
θ_f
445
DIGGING REACTION FORCE : F

FIG.8



420
424
410
P1
P0
P2
mg
mg cos θ m
mg cos(θ g+θ m)
θ m
θ g
θ t
l g
l t
441
443
445
Fsin(θ f+θ t)
θ f
DIGGING REACTION FORCE : F

FIG.9

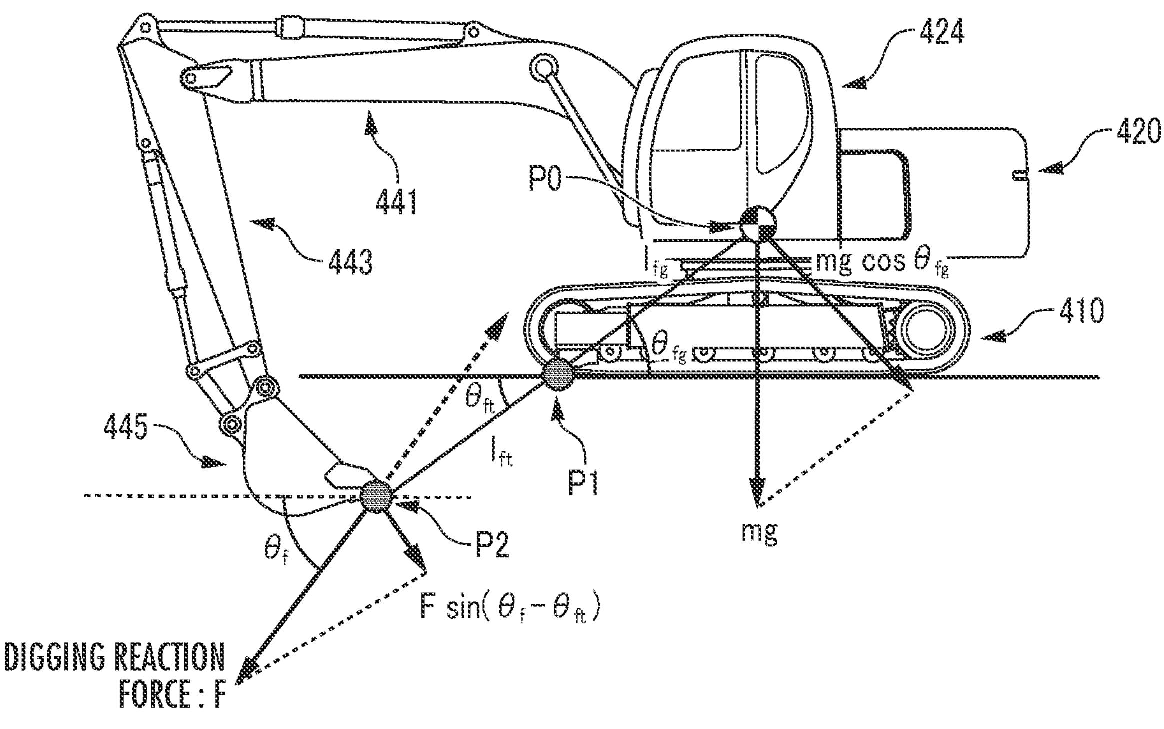

424
420
441
P0
443
l_{fg}
mg cos θ_{fg}
410
θ_{fg}
θ_{ft}
445
l_{ft}
P1
P2
θ_f
mg
F sin($\theta_f - \theta_{ft}$)
DIGGING REACTION
FORCE : F

FIG.10

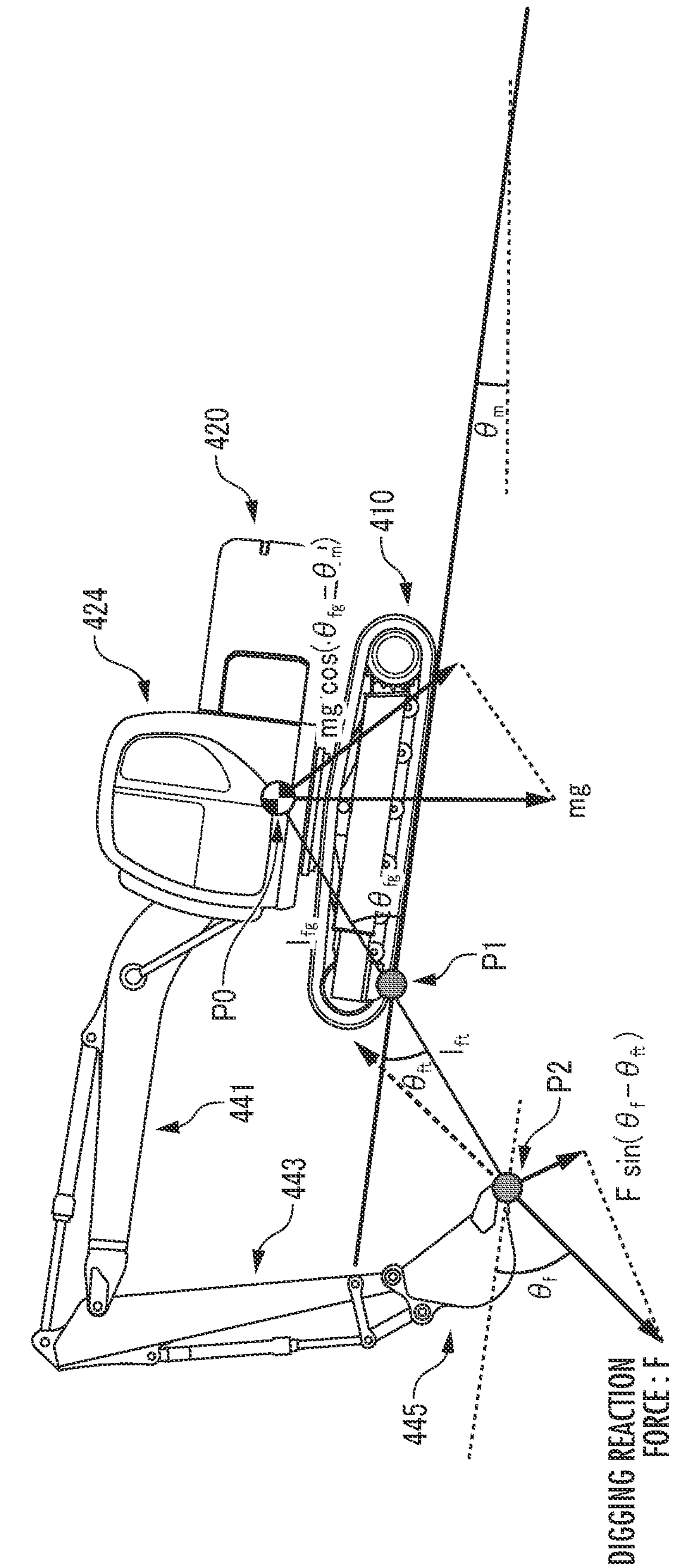

420
424
410
θm
mg·cos(θfg−θm)
mg
P0
θfg
lfg
P1
lft
θft
441
443
P2
F sin(θf−θft)
θf
445
DIGGING REACTION FORCE : F

FIG. 11

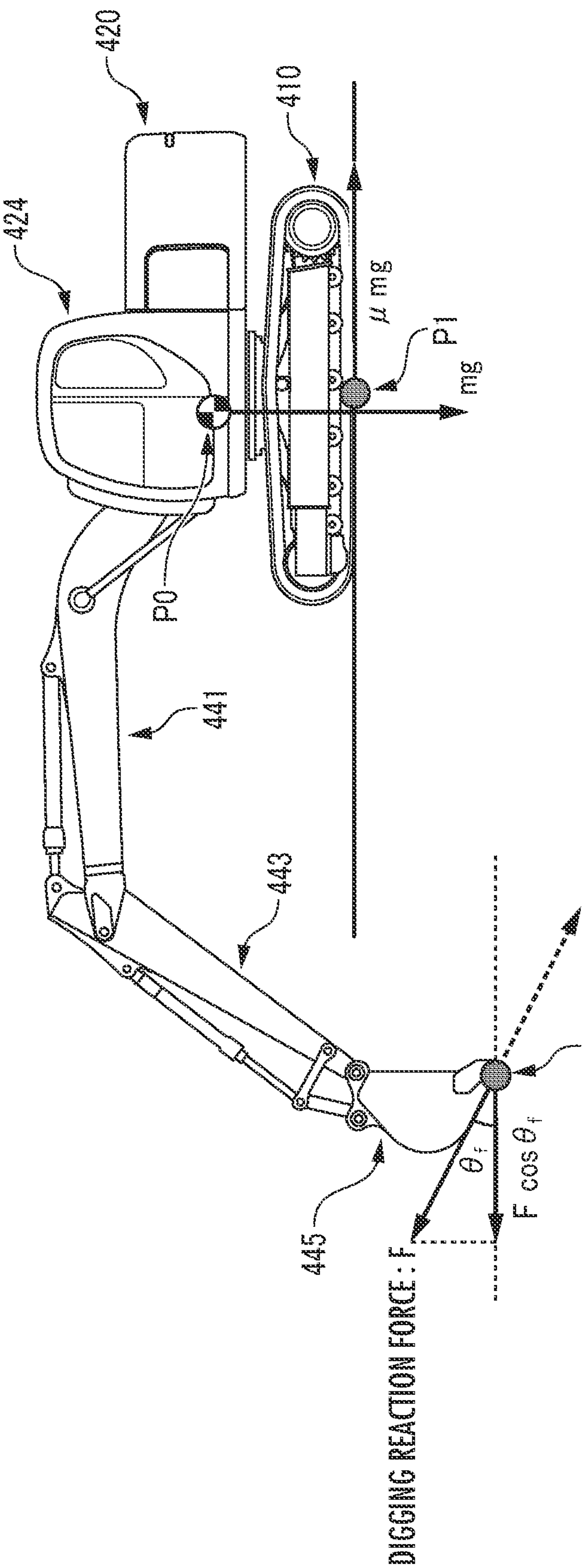

420
424
410
μ mg
P1
mg
P0
441
443
445
P2
θf
F cos θf
DIGGING REACTION FORCE : F

FIG.12

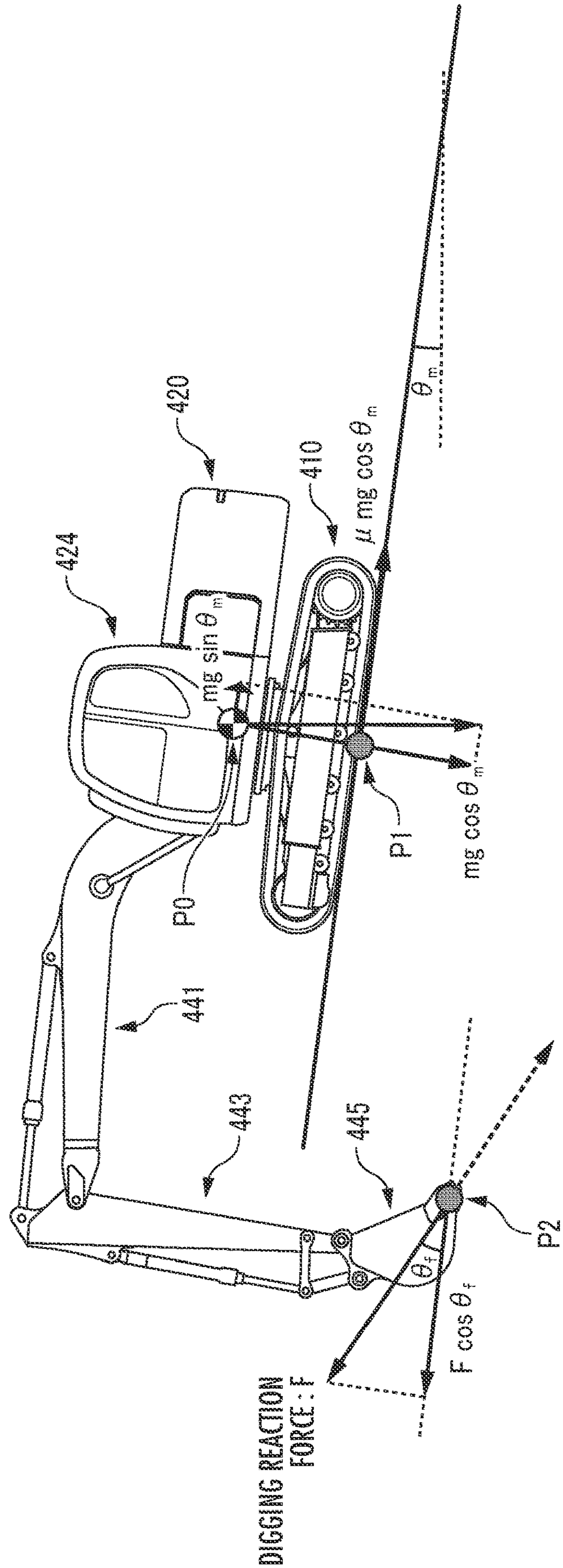
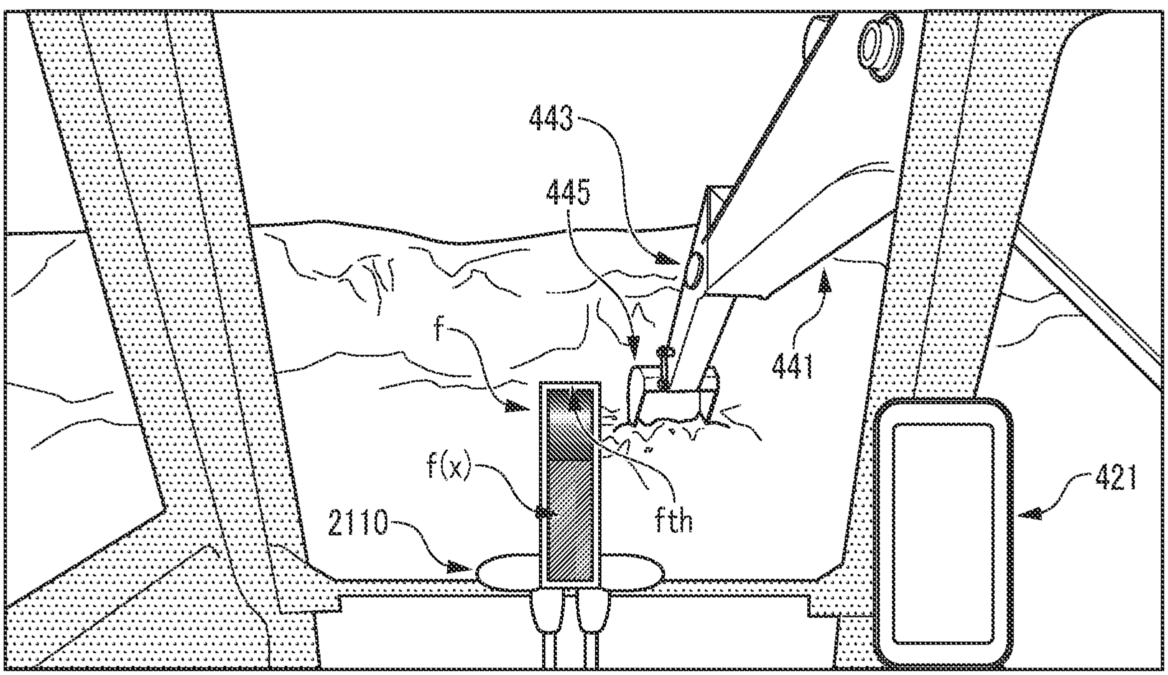

420
424
410
μ mg cos θ_m
θ_m
mg sin θ_m
P0
P1
mg cos θ_m
441
443
445
P2
θ_f
F cos θ_f
DIGGING REACTION FORCE : F

FIG.13



WORK MACHINE STATE MONITORING SYSTEM AND WORK MACHINE STATE MONITORING METHOD

TECHNICAL FIELD

The present invention relates to a system for monitoring a state of a work machine (actual machine).

BACKGROUND ART

There has been proposed an excavator which presents the degree of instability of the excavator to an operator, thereby making it possible to accurately determine an action that is not intended by the operator (see, for example, Patent Literature 1).

CITATION LIST

Patent Literature

Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2019-112783

SUMMARY OF INVENTION

Technical Problem

However, the degree of instability is presented as a discrete variable indicated, for example, in three ranges, and therefore, even when the operator uses the degree of instability as a reference, it is difficult to highly accurately grasp what degree of movement of each of a boom, an arm and a bucket causes a lower traveling body of the excavator to float up. Consequently, despite a situation in which the probability of occurrence of floating of the lower traveling body, i.e., the probability that the excavator becomes unstable is low, there is a possibility that the operator may stop further actions of the boom, etc., and the work efficiency may decrease.

Thus, an object of the present invention is to provide a system, which is provided for an operator of a work machine such as an excavator, and makes it possible to improve the accuracy of information relating to the degree of instability of the work machine.

Solution to Problem

An actual machine state monitoring system of the present invention is for causing an information output device to transmit a state of a work machine to an operator of the work machine, the work machining having a base body, a work mechanism extending from the base body, and a work part attached to a distal end of the work mechanism, the actual machine state monitoring system comprising:

an actual machine state recognition element which recognizes an attitude of the base body, and an external force acting on the work part;

an instability degree assessment element which assesses, based on the attitude of the base body and the external force acting on the work part recognized by the actual machine state recognition element, an instability degree of the base body as a continuous variable; and

an output control element which causes the information output device to output instability degree information such that a form of output of the instability degree information varies continuously depending on a con-

tinuous change in the instability degree, the instability degree information indicating the instability degree of the base body assessed by the instability degree assessment element.

According to the actual machine state monitoring system of this configuration, the instability degree information indicating the value of the instability degree of the base body assessed as a continuous variable is output to the information output device such that the form of the output varies continuously depending on a continuous change in the instability degree.

Therefore, it is possible to enable the operator of the work machine to highly accurately recognize the closeness of the current instability degree of the base body to a threshold value at which the base body becomes unstable, and consequently a tolerable range in which the work mechanism, etc. are operated while avoiding instability of the base body.

In order to cause the operator to recognize the instability degree through the operator's sense of vision, the output control element may cause an image output device constituting the information output device to output a diagram showing the instability degree of the base body such that the form of the diagram varies continuously based on a threshold value of the instability degree as a criterion. In order to cause the operator to recognize the instability degree through the operator's sense of hearing, the output control element may cause a sound output device constituting the information output device to output a sound indicating the instability degree of the base body such that volume, frequency, or a combination of the volume and frequency of the sound varies continuously. In order to cause the operator to recognize the instability degree through the operator's sense of touch, the output control element may cause a vibration output device constituting the information output device to output a vibration indicating the instability degree of the base body such that amplitude, vibration frequency, or a combination of the amplitude and vibration frequency of the vibration varies continuously.

The actual machine state monitoring system of the present invention may be constituted by a remote operation assistant server for assisting, based on communications with each of the work machine and a remote operation device for remotely operating the work machine, a remote operation of the work machine by the remote operation device. The information output device may be constituted by the remote operation device for remotely operating the work machine.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is an explanatory view about a configuration of an actual machine state monitoring system as an embodiment of the present invention.

FIG. **2** is an explanatory view about a configuration of a remote operation device.

FIG. **3** is an explanatory view about a configuration of a work machine.

FIG. **4** is an explanatory view about a function of a remote operating system.

FIG. **5** is an explanatory view about a function of the actual machine state monitoring system.

FIG. **6** is an explanatory view about a work environment image.

FIG. **7** is an explanatory view about an assessment method for a first instability degree when the ground is flat.

FIG. **8** is an explanatory view about an assessment method for the first instability degree when the ground is inclined.

FIG. **9** is an explanatory view about an assessment method for a second instability degree when the ground is flat.

FIG. **10** is an explanatory view about an assessment method for the second instability degree when the ground is inclined.

FIG. **11** is an explanatory view about an assessment method for a third instability degree when the ground is flat.

FIG. **12** is an explanatory view about an assessment method for the third instability degree when the ground is inclined.

FIG. **13** is an explanatory view about the form of output of instability degree information.

DESCRIPTION OF EMBODIMENTS

(Configuration of Remote Operating System)

An actual machine state monitoring system **110** as an embodiment of the present invention shown in FIG. **1** is constituted by a remote operation assistant server **10** for assisting a remote operation of a work machine **40** by a remote operation device **20**. The remote operation assistant server **10** and the remote operation device **20** are configured to be able to communicate with each other through a first network. The remote operation assistant server **10** and the work machine **40** are configured to be able to communicate with each other through a second network. The first network and the second network may be networks adopting the same common communication standard, or networks adopting mutually different communication standards.

(Configuration of Remote Operation Assistant Server)

The remote operation assistant server **10** includes a database **102**, the actual machine state monitoring system **110**, a first assistant processing element **121**, and a second assistant processing element **122**. The database **102** stores and retains captured image data, etc. The database **102** may be constituted by a database server different from the remote operation assistant server **10**. Each of the assistant processing elements is constituted by an arithmetic processing device (a single-core processor, or a multi-core processor or a processor core constituting the same), reads necessary data and software from a storage device such as a memory, and executes later-described arithmetic processing on the data, according to the software.

(Configuration of Actual Machine State Monitoring System)

The actual machine state monitoring system **110** comprises an actual machine state recognition element **111**, an instability degree assessment element **112**, and an output control element **114**. Each of the elements is constituted by an arithmetic processing device (a single-core processor, or a multi-core processor or a processor core constituting the same), reads necessary data and software from a storage device such as a memory, and executes later-described arithmetic processing on the data, according to the software.

(Configuration of Remote Operation Device)

The remote operation device **20** comprises a remote control device **200**, a remote input interface **210**, and a remote output interface **220**. The remote control device **200** is constituted by an arithmetic processing device (a single-core processor, or a multi-core processor or a processor core constituting the same), reads necessary data and software from a storage device such as a memory, and executes arithmetic processing on the data, according to the software.

The remote input interface **210** comprises a remote operating mechanism **211**. The remote output interface **220** comprises a remote image output device **221**, a sound output device **222**, a vibration output device **223**, and a remote wireless communication device **224**. Each of the remote image output device **221**, the sound output device **222**, and the vibration output device **223** constitutes an "information output device". Some of the remote image output device **221**, the sound output device **222**, and the vibration output device **223** may be omitted.

The remote operating mechanism **211** includes a traveling operating device, a turning operating device, a boom operating device, an arm operating device, and a bucket operating device. Each of the operating devices has an operating lever which receives a pivoting operation. The operating lever (travel lever) of the traveling operating device is operated to move a lower traveling body **410** of the work machine **40**. The travel lever may also function as a travel pedal. For example, a travel pedal which is fixed to a base portion or a lower end portion of the travel lever may be provided. The operating lever (turn lever) of the turning operating device is operated to move a hydraulic turning motor constituting a turning mechanism **430** of the work machine **40**. The operating lever (boom lever) of the boom operating device is operated to move a boom cylinder **442** of the work machine **40**. The operating lever (arm lever) of the arm operating device is operated to move an arm cylinder **444** of the work machine **40**. The operating lever (bucket lever) of the bucket operating device is operated to move a bucket cylinder **446** of the work machine **40**.

As shown in FIG. **2**, for example, the operating levers constituting the remote operating mechanism **211** are disposed around a seat St on which the operator sits. The seat St is in the form of a high back chair with arm rests, but may be a seat in any form on which the operator can sit, such as a low back chair without a head rest, or a chair without a backrest.

A pair of left and right travel levers **2110** corresponding to left and right crawlers are disposed side by side on the left side and right side in front of the seat St. One operating lever may function as a plurality of operating levers. For example, the left-side operating lever **2111** mounted at the front of a left-side frame of the seat St shown in FIG. **2** may function as an arm lever when the left-side operating lever **2111** is operated in a front-rear direction, and also function as a turn lever when the left-side operating lever **2111** is operated in a left-right direction. Similarly, aright-side operating lever **2112** mounted at the front of a right-side frame of the seat St shown in FIG. **2** may function as a boom lever when the right-side operating lever **2112** is operated in the front-rear direction, and also function as a bucket lever when the right-side operating lever **2112** is operated in the left-right direction. A lever pattern may be arbitrarily changed according to an operation instruction from the operator.

For example, as shown in FIG. **2**, the remote image output device **221** is constituted by a central remote image output device **2210**, a left-side remote image output device **2211**, and a right-side remote image output device **2212** disposed in front, on the diagonally front left side, and the diagonally front right side, respectively, of the seat St, each remote image output device having a substantially rectangular screen. The screens (image display areas) of the central remote image output device **2210**, the left-side remote image output device **2211**, and the right-side remote image output device **2212** may have the same shape and size, or different shapes and sizes.

As shown in FIG. **2**, the right edge of the left-side remote image output device **2211** is adjacent to the left edge of the central remote image output device **2210** such that the screen of the central remote image output device **2210** and the screen of the left-side remote image output device **2211** form an inclination angle θ1 (for example, 120°≤θ1≤150°). As shown in FIG. 2, the left edge of the right-side remote image output device **2212** is adjacent to the right edge of the central remote image output device **2210** such that the screen of the central remote image output device **2210** and the screen of the right-side remote image output device **2212** form an inclination angle θ2 (for example, 120°≤θ2≤150°). The inclination angles θ1 and θ2 may be the same, or different from each other.

The screens of the central remote image output device **2210**, the left-side remote image output device **2211**, and the right-side remote image output device **2212** may be parallel to a vertical direction, or inclined with respect to the vertical direction. At least one image output device among the central remote image output device **2210**, the left-side remote image output device **2211**, and the right-side remote image output device **2212** may be constituted by a plurality of split image output devices. For example, the central remote image output device **2210** may be constituted by a pair of image output devices which have substantially rectangular screens and are disposed adjacent to each other in the up-down direction.

The sound output device **222** is constituted by one or a plurality of speakers, and, for example, as shown in FIG. **2**, is constituted by a central sound output device **2220**, a left-side sound output device **2221**, and a right-side sound output device **2222** disposed behind the seat St, behind the left armrest, and behind the right armrest, respectively. The specifications of the central sound output device **2220**, the left-side sound output device **2221**, and the right-side sound output device **2222** may be the same, or different from each other.

The vibration output device **223** is constituted by a piezoelectric element, and disposed or buried at one or a plurality of points of the seat St. When the vibration output device **223** vibrates, the operator sitting on the seat St can recognize the vibration mode through the sense of touch. The vibration output device **223** may be installed at any place touchable by the operator to recognize vibration, such as a remote operating lever constituting the remote operating mechanism **211**.

(Configuration of Work Machine)

The work machine **40** comprises an actual machine control device **400**, an actual machine input interface **41**, an actual machine output interface **42**, and a work mechanism **440**. The actual machine control device **400** is constituted by an arithmetic processing device (a single-core processor, or a multi-core processor or a processor core constituting the same), reads necessary data and software from a storage device such as a memory, and executes arithmetic processing on the data, according to the software.

The work machine **40** is, for example, a crawler excavator (construction machine) of hydraulic type, electric type, or hybrid driven type produced by a hydraulic-electric combination, and, as shown in FIG. **3**, comprises a crawler type lower traveling body **410**, and an upper turning body **420** mounted on the lower traveling body **410** via a turning mechanism **430** so as to be able to turn. A cab **424** (driver's cabin) is mounted on the front left side of the upper turning body **420**. The work mechanism **440** is mounted at the front center of the upper turning body **420**.

The actual machine input interface **41** comprises an actual machine operating mechanism **411**, an actual machine image capturing device **412**, and an actual machine state sensor group **414**. The actual machine operating mechanism **411** comprises a plurality of operating levers disposed in the same manner as the remote operating mechanism **211**, around the seat installed in the cab **424**. Installed in the cab **424** is a driving mechanism or a robot that receives a signal corresponding to an operation state of a remote operating lever, and moves an actual machine operating lever based on the received signal. The actual machine image capturing device **412** is installed, for example, in the cab **424**, and captures an image of the environment including at least a portion of the work mechanism **440**, through a front window and a pair of left and right side windows. Some or the whole of the front window (or window frame) and the side windows may be omitted. The actual machine state sensor group **414** is constituted by angle sensors for measuring a pivoting angle (elevation angle) of the boom **441** with respect to the upper turning body **420**, a pivoting angle of the arm **443** with respect to the boom **441**, and a pivoting angle of the bucket **445** with respect to the arm **443**, respectively, a turning angle sensor for measuring a turning angle of the upper turning body **420** with respect to the lower traveling body **410**, an external force sensor for measuring an external force acting on the bucket **445**, a three-axis acceleration sensor for measuring three-axis acceleration acting on the upper turning body **420**, etc.

The actual machine output interface **42** comprises an actual machine image output device **421**, and an actual machine wireless communication device **422**. The actual machine image output device **421** is disposed, for example, in the vicinity of the front window in the cab **424** (see FIG. **6** and FIG. **9**). The actual machine image output device **421** may be omitted.

The work mechanism **440** as an operating mechanism comprises the boom **441** attached to the upper turning body **420** so as to be able to elevate, the arm **443** pivotably connected to a distal end of the boom **441**, and the bucket **445** pivotably connected to a distal end of the arm **443**. Attached to the work mechanism **440** are the boom cylinder **442**, the arm cylinder **444**, and the bucket cylinder **446**, each being constituted by an extendable hydraulic cylinder. As a work part, various attachments such as a nibbler, a cutter, and a magnet as well as the bucket **445** may be used.

The boom cylinder **442** is interposed between the boom **441** and the upper turning body **420** such that the boom cylinder **442** is extended and shortened by receiving a supply of hydraulic oil, and pivots the boom **441** in an elevating direction. The arm cylinder **444** is interposed between the arm **443** and the boom **441** such that the arm cylinder **444** is extended and shortened by receiving a supply of hydraulic oil, and pivots the arm **443** around a horizontal axis with respect to the boom **441**. The bucket cylinder **446** is interposed between the bucket **445** and the arm **443** such that the bucket cylinder **446** is extended and shortened by receiving a supply of hydraulic oil, and pivots the bucket **445** around a horizontal axis with respect to the arm **443**.

(First Function)

A first function of a remote operation assisting system constituted by the remote operation assistant server **10**, the remote operation device **20** and the work machine **40** of the above configuration will be described using a flowchart shown in FIG. **4**. In the flowchart, the blocks "C •" are used for simplifying the description, and mean transmission and/or reception of data, and mean conditional branches to execute processing in branch direction under the condition of transmitting and/or receiving the data.

In the remote operation device **20**, it is decided whether there is a specifying operation through the remote input interface **210** by an operator (STEP **210** in FIG. **4**). The "specifying operation" is, for example, an operation, such as tapping the remote input interface **210** performed by the operator to specify the work machine **40** that the operator intends to remotely operate. If the result of the decision is no (NO in STEP **210** in FIG. **4**), a sequence of processing is finished. On the other hand, if the result of the decision is yes (YES in STEP **210** in FIG. **4**), an environment confirmation request is transmitted to the remote operation assistant server **10** through the remote wireless communication device **224** (STEP **212** in FIG. **4**).

In the remote operation assistant server **10**, when the environment confirmation request is received, the environment confirmation request is transmitted to the corresponding work machine **40** by the first assistant processing element **121** (C**10** in FIG. **4**).

In the work machine **40**, when the environment confirmation request is received through the actual machine wireless communication device **422** (C**40** in FIG. **4**), the actual machine control device **400** acquires a captured image through the actual machine image capturing device **412** (STEP **410** in FIG. **4**). Captured image data representing the captured image is transmitted through the actual machine wireless communication device **422** to the remote operation assistant server **10** by the actual machine control device **400** (STEP **412** in FIG. **4**).

In the remote operation assistant server **10**, when the captured image data is received by the first assistant processing element **121** (C**11** in FIG. **4**), environment image data corresponding to the captured image is transmitted to the remote operation device **20** by the second assistant processing element **122** (STEP **110** in FIG. **4**). The environment image data is image data representing a simulated environment image generated based on the captured image, as well as the captured image data itself.

In the remote operation device **20**, when the environment image data is received through the remote wireless communication device **224** (C**21** in FIG. **4**), an environment image corresponding to the environment image data is transmitted to the remote image output device **221** by the remote control device **200** (STEP **214** in FIG. **4**).

Consequently, for example, as shown in FIG. **6**, the environment image in which the boom **441**, the arm **443**, and the bucket **445** as parts of the work mechanism **440** appear is output to the remote image output device **221**.

In the remote operation device **20**, an operation mode of the remote operating mechanism **211** is recognized by the remote control device **200** (STEP **216** in FIG. **4**), and a remote operation command corresponding to the operation mode is transmitted to the remote operation assistant server **10** through the remote wireless communication device **224** (STEP **218** in FIG. **4**).

In the remote operation assistant server **10**, when the remote operation command is received by the second assistant processing element **122**, the remote control operation command is transmitted to the work machine **40** by the first assistant processing element **121** (C**12** in FIG. **4**).

In the work machine **40**, when the operation command is received by the actual machine control device **400** through the actual machine wireless communication device **422** (C**41** in FIG. **4**), actions of the work mechanism **440** are controlled (STEP **414** in FIG. **4**). For example, work of scooping soil in front of the work machine **40** by the bucket **445**, and dropping the soil from the bucket **445** after turning the upper turning body **420** is executed.

A second function of the remote operation assisting system of the above configuration (mainly the function of the actual machine state monitoring system **110** constituted by the remote operation assistant server **10**) will be described using a flowchart shown in FIG. **5**. In the flowchart, the blocks "C •" are used for simplifying the description, and mean transmission and/or reception of data, and mean conditional branches to execute processing in branch direction under the condition of transmitting and/or receiving the data.

In the work machine **40**, actual machine state data representing an operation state of the work machine **40** is acquired by the actual machine control device **400**, based on an output signal from the actual machine state sensor group **414** (STEP **420** in FIG. **5**). The operation state of the work machine **40** includes the pivoting angle (elevation angle) of the boom **441** with respect to the upper turning body **420**, the pivoting angle of the arm **443** with respect to the boom **441**, the pivoting angle of the bucket **445** with respect to the arm **443**, the turning angle of the upper turning body **420** with respect to the lower traveling body **410**, and an external force F acting on the bucket **445**, etc.

The actual machine state data is transmitted through the actual machine wireless communication device **422** to the remote operation assistant server **10** by the actual machine control device **400** (STEP **422** in FIG. **5**).

In the remote operation assistant server **10**, when the actual machine state data is received (C**14** in FIG. **5**), the state of the work machine **40** is recognized based on the actual machine state data by the actual machine state recognition element **111** (STEP **120** in FIG. **5**).

More specifically, the time sequence of the external force F acting on the bucket **445** is recognized. The external force F may be recognized depending on at least one hydraulic pressure of the boom cylinder **442**, the arm cylinder **444**, and the bucket cylinder **446**.

Moreover, in the actual machine coordinate system when the position and attitude with respect to the work machine **40** are fixed, each of coordinate values of a gravity center P0 of a base body constituted by the lower traveling body **410** and the upper turning body **420**, a floating fulcrum point P1, and an external force action point P2 (distal end point of the bucket **445**) is recognized. The coordinate values of the gravity center P0 of the base body in the actual machine coordinate system are classified by each type and/or specification of the work machine **40**, and preregistered in the database **102**. The coordinate values of the floating fulcrum point P1 in the actual machine coordinate system are recognized based on the turning angle of the upper turning body **420** with respect to the lower traveling body **410** (see a floating fulcrum point T1f in Patent Literature 1). The external force action point P2 in the actual machine coordinate system is geometrically recognized based on each of the pivoting angle (elevation angle) of the boom **441** with respect to the upper turning body **420**, the pivoting angle of the arm **443** with respect to the boom **441**, the pivoting angle of the bucket **445** with respect to the arm **443**, and link lengths of the boom **441**, the arm **443**, and the bucket **445**. Each of the link length of the boom **441** (the distance from a joint mechanism on the upper turning body **420** side to a joint mechanism on the arm **443** side), the link length of the arm **443** (the distance from a joint mechanism on the boom **441** side to a joint mechanism on the bucket **445** side), and the link length of the bucket **445** (the distance from a joint mechanism on the arm **443** side to the distal end of the bucket **445**) is classified by each type and/or specification of the work machine **40**, and preregistered in the database **102**.

Whether or not the work machine **40** is executing specified work using the bucket **445** (work part) is decided by the actual machine state recognition element **111** (STEP **121** in FIG. **5**). For example, if the specified work is digging work, whether or not the work machine **40** is executing the specified work is recognized, based on whether or not the external force F acting on the bucket **445** repetitively increases and decreases.

If the result of the decision is no (NO in STEP **121** in FIG. **5**), a sequence of processing in this control cycle is finished. On the other hand, if the result of the decisions is yes (YES in STEP **121** in FIG. **5**), a first instability degree Is**1**, a second instability degree Is**2**, and a third instability degree Is**3** of the upper turning body **420** (base body) of the work machine **40** are assessed by the instability degree assessment element **112**, based on the actual machine state recognized by the actual machine state recognition element **111** (STEP **122** in FIG. **5**).

The first instability degree Is**1** represents an instability degree defined from a viewpoint of instability of the base body due to floating up of the lower traveling body **410** (base body) of the work machine **40** from the ground. The first instability degree Is**1** is given by a relational expression (11), based on the external force F, an angle θ_f formed by an external force vector with a horizontal plane, a distance I_g between the gravity center P0 of the base body and the floating fulcrum point P1 located behind the gravity center P0, a distance I_t between the floating fulcrum point P1 and the external force action point P2, an angle θ_g formed by a line segment P0-P1 (or a plane including the line segment P0-P1) with the horizontal plane, an angle θ_t formed by a line segment P1-P2 (or a plane including the line segment P1-P2) with the horizontal plane, a weight m of the base body, and gravitational acceleration g shown in FIG. **7**. In short, the first instability degree Is**1** is defined as a continuous function or a continuous dependent variable with continuous variables It, F, θ_f, θ_t, I_g, and θ_g as main variables.

$$Is1=I_t\cdot F\ \sin(\theta_t+\theta_f)/I_g\cdot mg\ \cos\ \theta_g \qquad (11).$$

As shown in FIG. **8**, when the ground is inclined only by an angle θ_m, the first instability degree Is**1** is defined by a relational expression (21). The inclination angle θ_m of the ground is measurable based on output signals from the three-axis acceleration sensor that constitutes the actual machine state sensor group **414**, and measures three-axis acceleration acting on the upper turning body **420**.

$$Is1=I_t\cdot F\ \sin(\theta_t+\theta_f)/I_g\cdot mg\ \cos(\theta_g+\theta_m) \qquad (21).$$

The second instability degree Is**2** represents an instability degree defined from a viewpoint of instability of the base body due to floating up of the lower traveling body **410** (base body) of the work machine **40** from the ground. The second instability degree Is**2** is given by a relational expression (12), based on the external force F, the angle θ_f formed by the external force vector with the horizontal plane, a distance I_{fg} between the gravity center P0 of the base body and the floating fulcrum point P1 located in front of the gravity center P0, a distance I_f between the floating fulcrum point P1 and the external force action point P2, an angle θ_{fg} formed by the line segment P0-P1 (or a plane including the line segment P0-P1) with the horizontal plane, an angle $\theta_f t$ formed by the line segment P1-P2 (or a plane including the line segment P1-P2) with the horizontal plane, the weight m of the base body, and the gravitational acceleration g shown in FIG. **9**. In short, the second instability degree Is**2** is defined as a continuous function or a continuous dependent variable with continuous variables I_f, F, θ_f, θ_t, I_{fg}, and θ_{fg} as main variables.

$$Is2=I_{ft}\cdot F\ \sin(\theta_f-\theta_f t)/I_{fg}\cdot mg\ \cos\ \theta_{fg} \qquad (12).$$

As shown in FIG. **10**, when the ground is inclined only by the angle θ_m, the second instability degree Is**2** is defined by a relational expression (22).

$$Is2=I_{ft}\cdot F\ \sin(\theta_f-\theta_f t)/I_{fg}\cdot mg\ \cos(\theta_{fg}+\theta_m) \qquad (22).$$

The third instability degree Is**3** represents an instability degree defined from a viewpoint of instability of the base body caused when the lower traveling body **410** (base body) of the work machine **40** slides with respect to the ground. The third instability degree Is**3** is given by a relational expression (13), based on the external force F, the angle θ_f formed by the external force vector with the horizontal plane, the weight m of the base body, the gravitational acceleration g, and a static friction coefficient (or dynamic friction coefficient) between the base body and the ground shown in FIG. **11**. In short, the third instability degree Is**3** is defined as a continuous function or a continuous dependent variable with continuous variables F and θ_f as main variables. It should be noted that, for the static friction coefficient μ, a standard value at the work site is used, but different values may be used depending on different meteorological conditions (precipitation, temperature, humidity, etc.), and/or soil conditions and ground conditions (dirt, clay, gravel, sand, debris, etc.).

$$Is3=F\ \cos\ \theta_f/mg \qquad (13).$$

As shown in FIG. **12**, when the ground is inclined only by an angle θ_m, the third instability degree Is**3** is defined by a relational expression (23).

$$Is3=F\ \cos\ \theta_f/(\mu mg\ \cos\ \theta_m-mg\ \sin\theta_m) \qquad (23).$$

Which of the first instability degree Is**1**, the second instability degree Is**2**, and the third instability degree Is**3** is maximum is decided by the output control element **114** (STEP **124** in FIG. **5**).

If it is decided that the first instability degree Is**1** is maximum instability Ismax (**1** in STEP **124** in FIG. **5**), first instability degree information indicating the first instability degree Is**1** is generated by the output control element **114** (STEP **125** in FIG. **5**). If it is decided that the second instability degree Is**2** is maximum instability Ismax (**2** in STEP **124** in FIG. **5**), second instability degree information indicating the second instability degree Is**2** is generated by the output control element **114** (STEP **126** in FIG. **5**). If it is decided that the third instability degree Is**3** is maximum instability Ismax (**3** in STEP **124** in FIG. **5**), third instability degree information indicating the third instability degree Is**3** is generated by the output control element **114** (STEP **127** in FIG. **5**). Then, the first instability degree information, the second instability degree information, or the third instability degree information is transmitted to the remote operation device **20** by the output control element **114** (STEP **128** in FIG. **5**).

In the remote operation device **20**, when the first instability degree information, the second instability degree information, or the third instability degree information is received by the remote wireless communication device **224** (C**22** in FIG. **5**), the instability degree information is output to the remote image output device **221** by the remote control device **200** (STEP **224** in FIG. **5**).

Consequently, as shown in FIG. **13**, for example, a diagram f(x) or bar graph in which the length from a lower edge of a window f varies depending on the level of the instability degree is output to the window f in a superimposed manner on the environment image on the remote image output device **221**. The size of the diagram f(x) is defined by an increasing function, such as a linear function, an exponential function, and a logarithmic function, with the instability degree as a variable. A scale division at or below the top edge of the window f represents a threshold value fth at which the base body floats up from the ground, or the base body slides with respect to the ground, when the first instability degree Is**1**, the second instability degree Is**2**, or the third instability degree Is**3** reaches the threshold value fth.

The diagram f(x) may take various shapes such as a circular shape, a circular-sector shape, and a rhombus shape, as well as a rectangular shape. The size, shape, color (lightness, saturation and hue) or pattern, or an arbitrary combination thereof of the diagram f(x) may be output so as to vary continuously depending on a continuous change in the instability degree Is**1**, Is**2**, Is**3**.

Effects

According to the actual machine state monitoring system **110** constituting the remote operation assisting system of this configuration, the instability degree information indicating the values of instability degrees Is**1**, Is**2**, Is**3** of the base body (the lower traveling body **410** and the upper turning body **420**) assessed as continuous variables is output to the remote image output device **221** (information output device) such that the form of the output varies continuously depending on continuous changes in the instability degrees Is**1**, Is**2**, Is**3** (see STEP **122** to STEP **224** in FIG. **5**, and FIG. **9**).

Therefore, it is possible to enable the operator of the work machine **40** to highly accurately recognize the closeness of the current instability degree of the base body to the threshold value at which the base body becomes unstable, and consequently a tolerable range in which the work mechanism, etc. are operated while avoiding instability of the base body.

Through the instability degree information (first instability degree information) indicating the first instability degree output by the information output device, it is possible to enable the operator of the work machine to highly accurately recognize the closeness of the first instability degree of the base body to the threshold value (first threshold value), and consequently a tolerable range in which the work mechanism, etc. are operated while avoiding instability of the base body due to floating up from the ground with the floating fulcrum P1 located behind the gravity center P0 as the start point (see FIG. **7**, HG, **8**, and FIG. **13**). Similarly, through the instability degree information (second instability degree information) indicating the second instability degree output by the information output device, it is possible to enable the operator of the work machine to highly accurately recognize the closeness of the second instability degree of the base body to the threshold value (second threshold value), and consequently a tolerable range in which the work mechanism, etc. are operated while avoiding instability of the base body due to floating up from the ground with the floating fulcrum P1 located in front of the gravity center P0 as the start point (see FIG. **9**, HG, **10**, and FIG. **13**). Through the instability degree information (third instability degree information) indicating the third instability degree output by the information output device, it is possible to enable the operator of the work machine to highly accurately recognize the closeness of the instability degree of the base body to the threshold value (third threshold value), and consequently a tolerable range in which the work mechanism, etc. are operated while avoiding instability of the base body due to sliding with respect to the ground (see FIG. **11**, FIG. **12**, and FIG. **13**).

Moreover, only in a situation in which the work machine **40** is executing digging work as specified work while causing the bucket **445** (work part) to apply a force onto a work object (such as dirt and rubble), i.e., a situation in which the base body is likely to be unstable, the instability degree information is transmitted through the information output device to the operator (see YES in STEP **121** to STEP **224** in FIG. **5**). Consequently, the usefulness of the instability degree information is improved.

Another Embodiment of Present Invention

In the above embodiment, the actual machine state monitoring system **110** is constituted by the remote operation assistant server **10**, but the actual machine state monitoring system **110** may be constituted by the remote operation device **20** and/or the work machine **40** as another embodiment. In other words, the remote operation device **20** and/or the work machine **40** may have functions as the actual machine state recognition element **111**, the instability degree assessment element **112**, and the output control element **114**.

In the above embodiment, the instability degree information is output through the remote image output device **221**, but the instability degree information may be additionally or alternatively output through the sound output device **222** and/or the vibration output device **223**. A sound indicating the instability degree of the base body may be output by the sound output device **222** such that volume, frequency, or a combination of the volume and frequency of the sound varies continuously. A vibration indicating the instability degree of the base body may be output by the vibration output device **223** such that amplitude, vibration frequency, or a combination of the amplitude and vibration frequency of the vibration varies continuously.

In the above embodiment, the first instability degree Is**1**, the second instability degree Is**2** and the third instability degree Is**3** are assessed (see STEP **122** in FIG. **5**, and FIG. **7** to FIG. **12**), but, as another embodiment, only one of the first instability degree Is**1**, the second instability degree Is**2** and the third instability degree Is**3** may be assessed, and instability degree information indicating the one instability degree may be transmitted to the information output device. The average value or the weighted sum of at least two of the first instability degree Is**1**, the second instability degree Is**2** and the third instability degree Is**3** may be assessed as a single instability degree.

In the above embodiment, only the instability degree information indicating one of the first instability degree Is**1**, the second instability degree Is**2** and the third instability degree Is**3** is output to the information output device (see **1** in STEP **124**→STEP **125**→STEP **128**→ . . . →STEP **224** in FIG. **5**, **2** in STEP **124**→STEP **126**→STEP **128**→ . . . →STEP **224** in FIGS. **5**, and **3** in STEP **124**→STEP **126**→STEP **127**→ . . . STEP **224** in FIG. **5**), but three or two pieces of instability degree information indicating all or two of the first instability degree Is**1**, the second instability degree Is**2** and the third instability degree Is**3** may be output to the information output device. In this case, two diagrams f(x) for showing each of the first instability degree Is**1**, the second instability degree Is**2** and the third instability degree Is**3** may be output. Specific processing of the maximum instability degree Ismax (see STEP **124** in FIG. **5**) is omitted.

In the above embodiment, the instability degree information is transmitted through the information output device to the operator only in a situation in which the work machine **40** is executing specified work (for example, digging work) using the bucket **445** (work part) (see YES in STEP **121**→ . . . STEP **244** in FIG. **5**), but, as another embodiment, the instability degree information may be transmitted through the information output device to the operator, irrespective of whether or not the work machine **40** is executing specified work.

In the actual machine state monitoring system, the instability degree assessment element preferably assesses at least one of the first instability degree which is assessed using a criterion that the base body does not float up from the ground, and the second instability degree which is assessed using a criterion that the base body does not slide with respect to the ground.

According to the actual machine state monitoring system of this configuration, it is possible to enable the operator of the work machine to highly accurately recognize, through the instability degree information (first instability degree information) indicating the first instability degree output by the information output device, the closeness of the first instability degree of the base body to the threshold value (first threshold value), and consequently a tolerable range in which the work mechanism, etc. are operated while avoiding instability of the base body due to floating up from the ground. Similarly, it is possible to enable the operator of the work machine to highly accurately recognize, through the instability degree information (second instability degree information) indicating the second instability degree output by the information output device, the closeness of the instability degree of the base body to the threshold value (second threshold value), and consequently a tolerable range in which the work mechanism, etc. are operated while avoiding instability of the base body due to sliding with respect to the ground.

In the actual machine state monitoring system of the present invention, it is preferred that the actual machine state recognition element recognize whether or not the work machine is executing specified work while the work machine causes the work part to apply a force onto a work object, and that the output control element cause the information output device to output the instability degree information on condition that the actual machine state recognition element recognizes that the work machine is executing the specified work.

According to the actual machine state monitoring system of this configuration, only in a situation in which the work machine is executing specified work while causing the work part to apply a force onto a work object, i.e., a situation in which the base body is likely to be unstable, the instability degree information is transmitted through the information output device to the operator.

Consequently, the usefulness of the instability degree information is improved.

REFERENCE SIGNS LIST

10 . . . remote operation assistant server, **20** . . . remote operation device, **200** . . . remote control device, **40** . . . work machine, **210** . . . remote input interface, **211** . . . remote operating mechanism, **220** . . . remote output interface, **221** . . . remote image output device (information output device), **222** . . . sound output device (information output device), **223** . . . vibration output device (information output device), **224** . . . remote wireless communication device, **41** . . . actual machine input interface, **412** . . . actual machine image capturing device, **414** . . . actual machine state sensor group, **42** . . . actual machine output interface, **421** . . . actual machine image output device (information output device), **422** . . . actual machine wireless communication device, **440** . . . work mechanism (work attachment), **445** . . . bucket (work part), **110** . . . actual machine state monitoring system, **111** . . . actual machine state recognition element, **112** . . . instability degree assessment element, **114** . . . output control element, **410** . . . lower traveling body (base body), Is**1** . . . first instability degree, Is**2** . . . second instability degree, Is**3** . . . third instability degree.

The invention claimed is:

1. A machine state monitoring system for causing an information output device to transmit a state of a work machine to an operator of the work machine, the work machine having a base body, a work mechanism extending from the base body, and a work part attached to a distal end of the work mechanism, the machine state monitoring system comprising: a machine state recognition element which recognizes an attitude of the base body, and an external force acting on the work part; an instability degree assessment element which assesses one of a first instability degree, which is assessed using a criterion that the base body does not float up from the ground, and a second instability degree, which is assess using a criterion that the base body does not slide with respect to the ground; and an output control element which causes the information output device to output instability degree information such that a form of output of the instability degree information varies continuously depending on a continuous change in the larger of the first instability degree and the second instability degree, the instability degree information indicating the larger of the first instability degree and the second instability degree of the base body assessed by the instability degree assessment element; wherein the output control element causes an image output device constituting the information output device to output a diagram showing the instability degree of the base body such that a form of the diagram varies continuously based on a threshold value of the instability degree as a criterion.

2. The machine state monitoring system according to claim **1**, wherein the first instability contains one of first instability degree which is assessed using a criterion that a front side of the base body does not float up from the ground, and another of instability degree which is assesses using a criterion that a back side of the base body does not float up from the ground, and the output control element causes the information output device to output instability degree information such that a form of output of the instability degree information varies continuously depending on a continuous change in the largest instability degree of one of the first instability degree, another of the first instability degree, and the second instability degree, the instability degree information indicating selectively the largest instability degree of the base body assessed by the instability degree assessment element.

3. The machine state monitoring system according to claim **1**, wherein the output control element causes a sound output device constituting the information output device to output a sound indicating the instability degree of the base body such that volume, frequency, or a combination of the volume and frequency of the sound varies continuously.

4. The machine state monitoring system according to claim **1**, wherein the output control element causes a vibration output device constituting the information output device to output a vibration indicating the instability degree of the base body such that amplitude, vibration frequency, or a combination of the amplitude and vibration frequency of the vibration varies continuously.

5. The machine state monitoring system according to claim **1**, wherein

the machine state recognition element recognizes whether or not the work machine is executing specified work while the work machine causes the work part to apply a force onto a work object, and

the output control element causes the information output device to output the instability degree information on condition that the machine state recognition element recognizes that the work machine is executing the specified work.

6. The machine state monitoring system according to claim **1**, wherein the machine state monitoring system is constituted by a remote operation assistant server for assisting, based on communications with each of the work machine and a remote operation device for remotely operating the work machine, a remote operation of the work machine by the remote operation device.

7. The machine state monitoring system according to claim **1**, wherein the information output device is constituted by a remote operation device for remotely operating the work machine.

8. A machine state monitoring method for causing an information output device to transmit a state of a work machine to an operator of the work machine, the work machine having a base body, a work mechanism extending from the base body, and a work part attached to a distal end of the work mechanism, the machine state monitoring method comprising: a machine state recognition element which recognizes an attitude of the base body, and an external force acting on the work part; an instability degree assessment element which assesses one of a first instability degree, which is assessed using a criterion that the base body does not float up from the ground, and a second instability degree, which is assess using a criterion that the base body does not slide with respect to the ground; and an output control element which causes the information output device to output instability degree information such that a form of output of the instability degree information varies continuously depending on a continuous change in the larger of the first instability degree and the second instability degree, the instability degree information indicating the larger of the first instability degree and the second instability degree of the base body assessed by the instability degree assessment element; wherein the output control element causes an image output device constituting the information output device to output a diagram showing the instability degree of the base body such that a form of the diagram varies continuously based on a threshold value of the instability degree as a criterion.

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