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(12) **United States Patent**
Nagakari

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(45) **Date of Patent: Aug. 12, 2025**

(54) **INFORMATION PROCESSING DEVICE, INFORMATION PROCESSING METHOD, AND PROGRAM**

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(72) Inventor: **Satoko Nagakari**, Tokyo (JP)

(73) Assignee: **SONY GROUP CORPORATION**, Tokyo (JP)

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B25J 13/08 (2006.01)
B25J 9/16 (2006.01)

(52) **U.S. Cl.**
CPC ***B25J 13/083*** (2013.01); ***B25J 9/1612*** (2013.01)

(58) **Field of Classification Search**
CPC B25J 9/16; B25J 13/083; B25J 9/1612; A45B 2009/002; A45B 2009/005;
(Continued)

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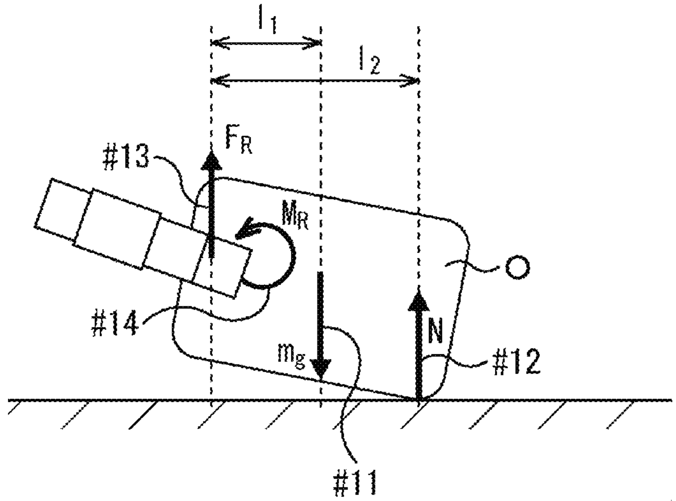
Primary Examiner — Adam R Mott
Assistant Examiner — James Miller Watts, III
(74) *Attorney, Agent, or Firm* — XSENSUS LLP

(57) **ABSTRACT**

An information processing device according to one aspect of the present technology detects a slip generated in an object being gripped by a finger portion constituting a grip portion, and estimates an external force and an external moment applied to the object on the basis of the slip generated in the object. In addition, the information processing device controls the operation of an arm portion on the basis of the estimated external force and external moment to adjust at least one of the position or the posture of the finger portion constituting the grip portion provided in the arm portion. The present technology can be applied to a control device of a robot hand.

13 Claims, 21 Drawing Sheets



(58) **Field of Classification Search**
CPC . A45B 2009/007; A45B 2200/05; A45B 5/00; A45B 9/00; A45B 9/02; A45B 9/04; A47C 13/00; A47C 9/10; G05B 2219/39505; G05B 2219/39507; G05B 2219/40264; G05B 2219/40625
USPC 700/245
See application file for complete search history.

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International Search Report and Written Opinion mailed on Oct. 26, 2021, received for PCT Application PCT/JP2021/029383, filed on Aug. 6, 2021, 11 pages including English Translation.

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FIG. 1

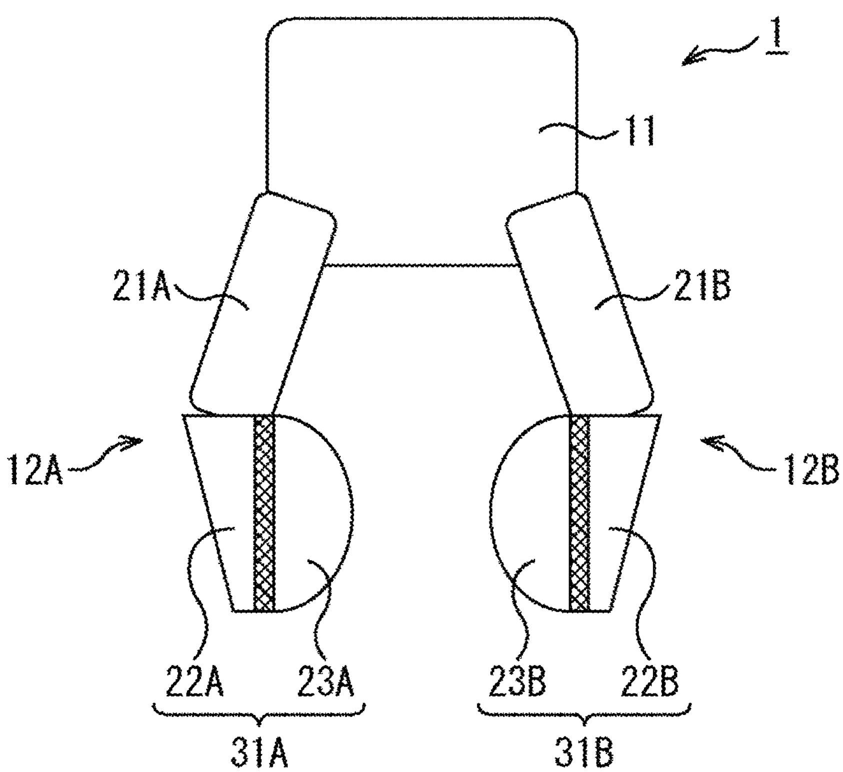


FIG. 2

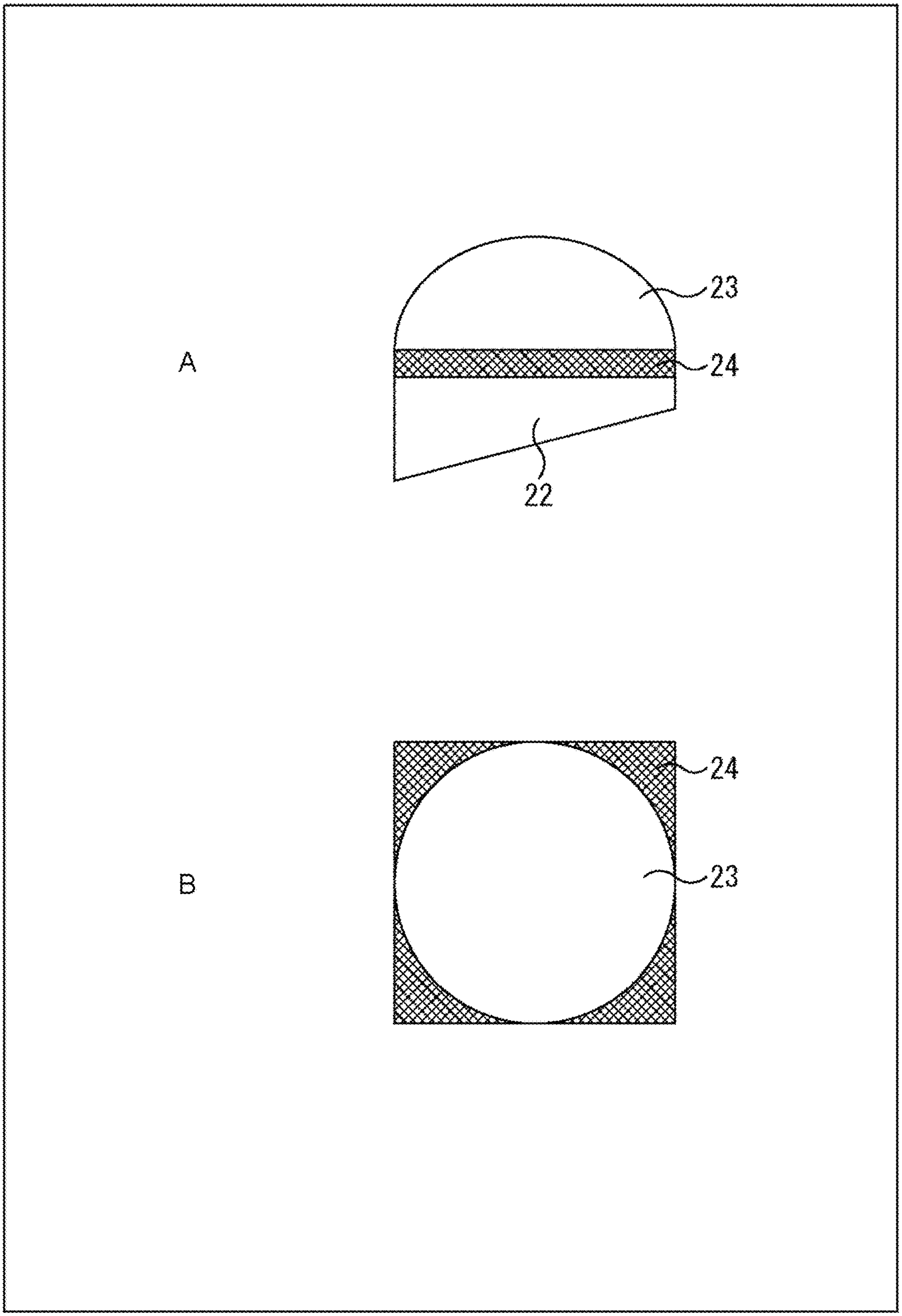


FIG. 3

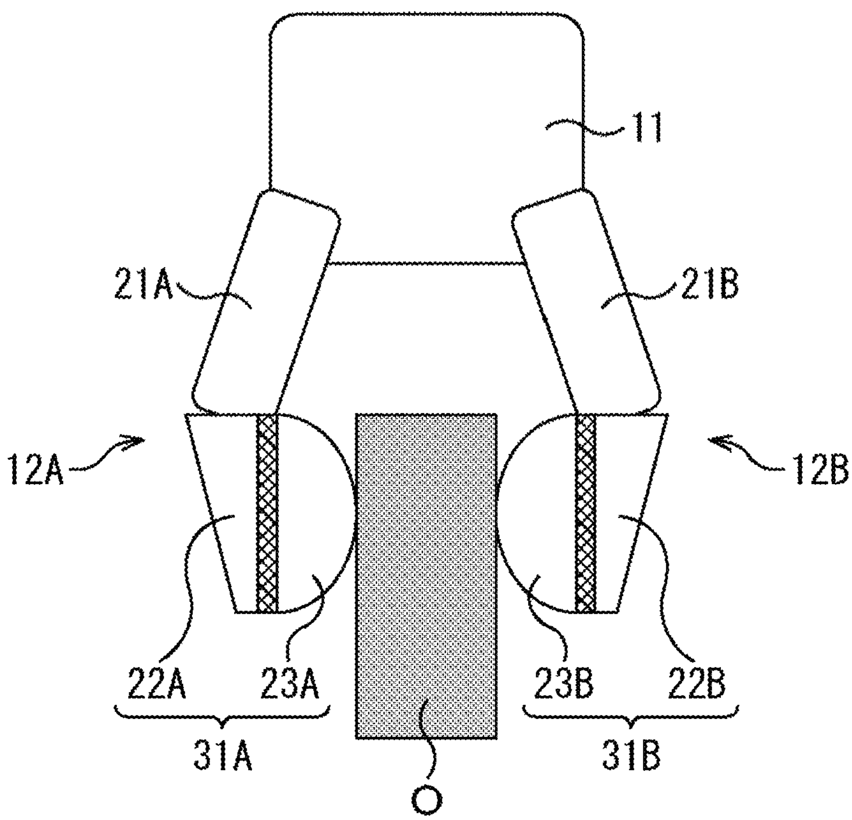


FIG. 4

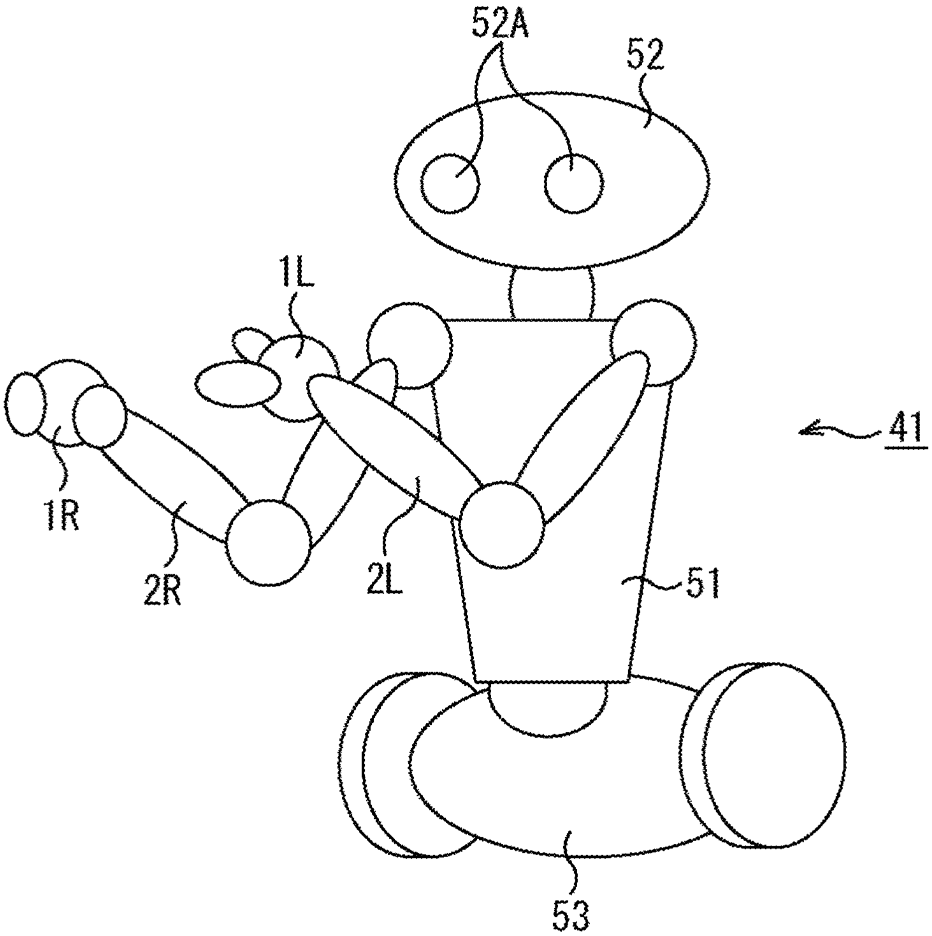


FIG. 5

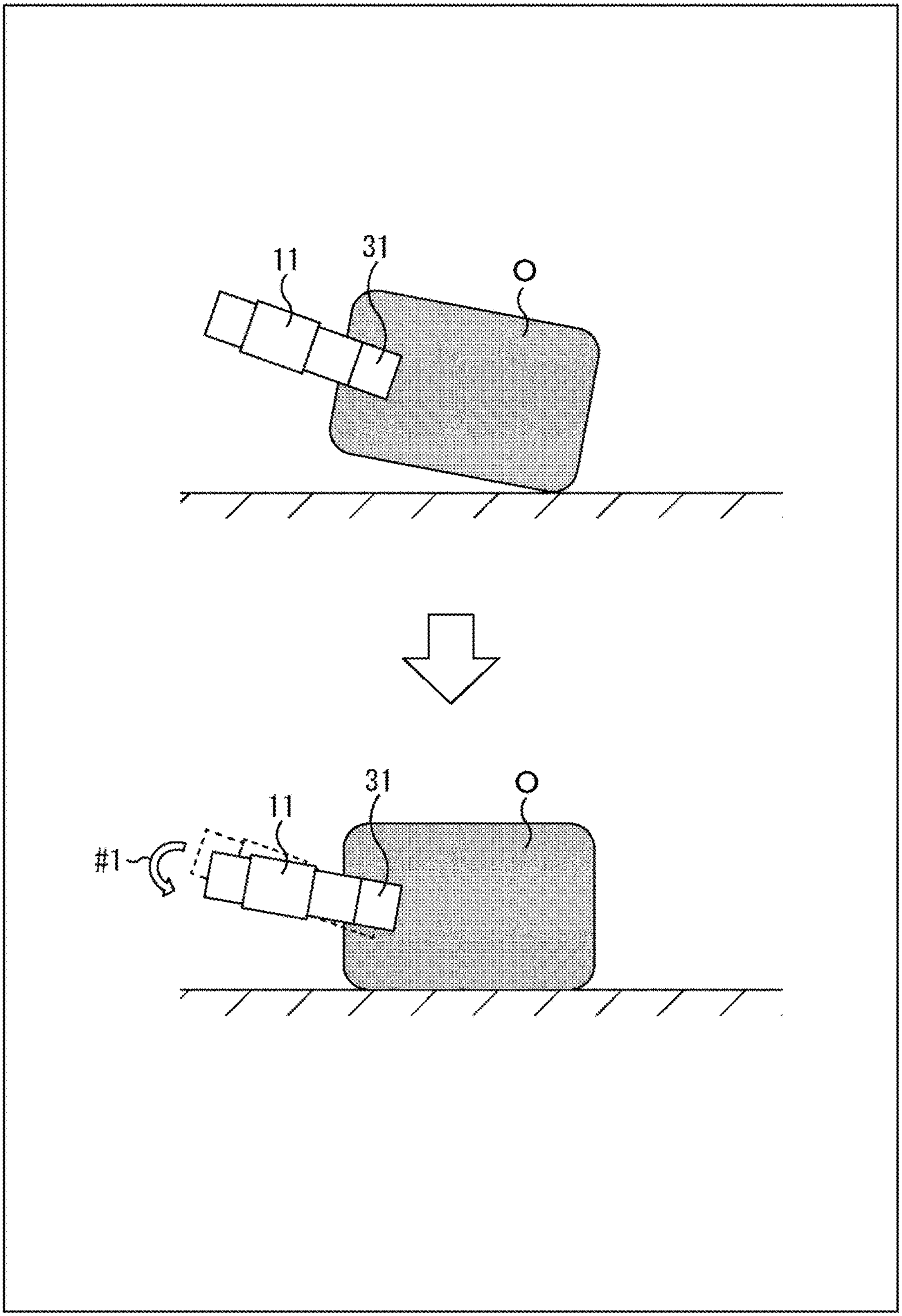


FIG. 6

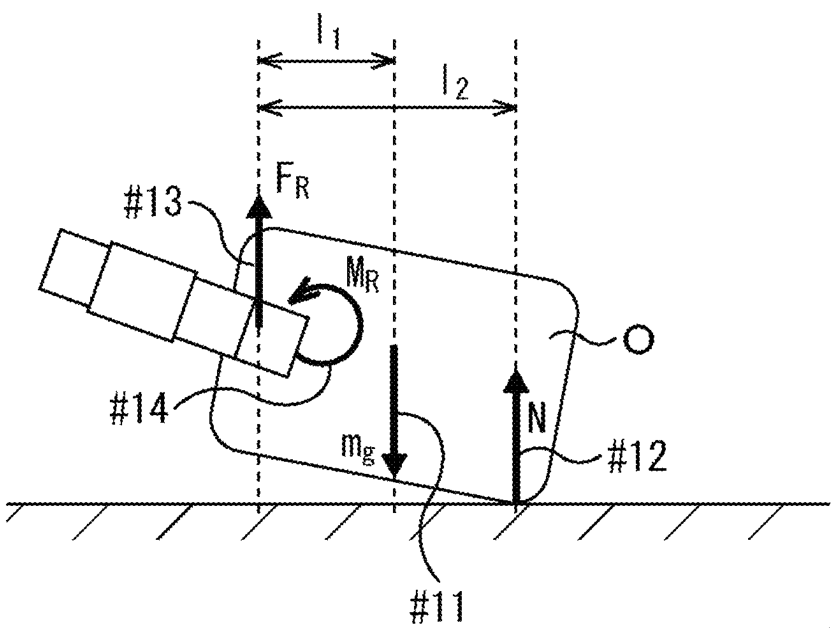


FIG. 7

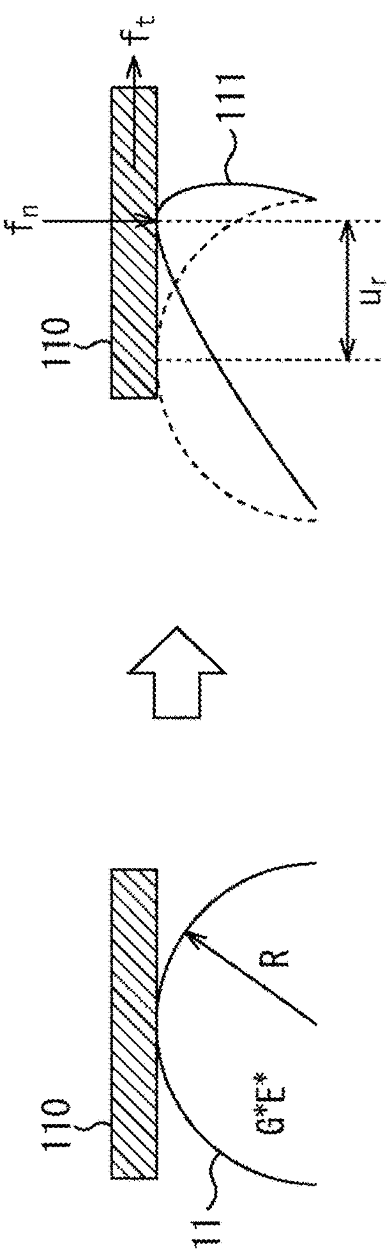


FIG. 8

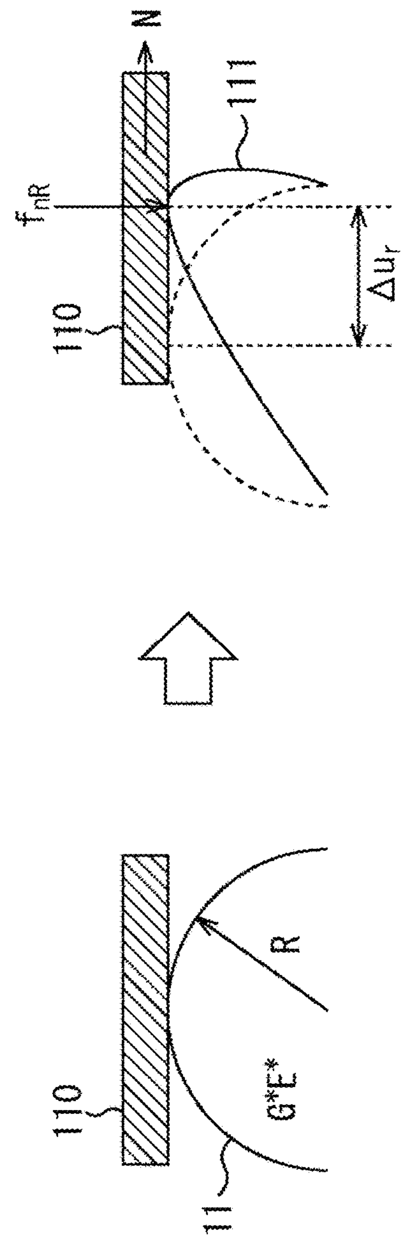


FIG. 9

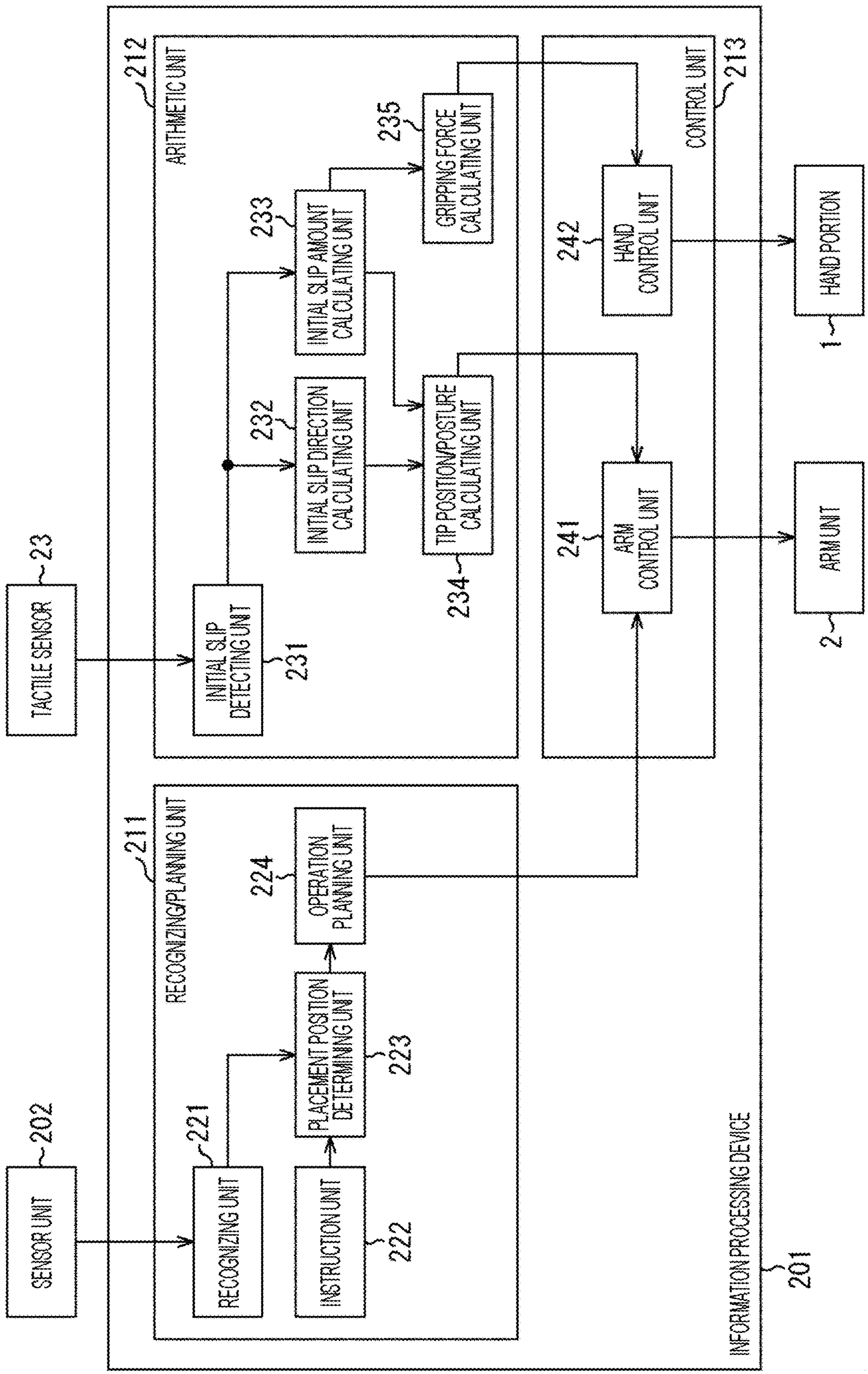

SENSOR UNIT
202
TACTILE SENSOR
23
RECOGNIZING/PLANNING UNIT
211
RECOGNIZING UNIT
221
INSTRUCTION UNIT
222
PLACEMENT POSITION DETERMINING UNIT
223
OPERATION PLANNING UNIT
224
ARITHMETIC UNIT
212
INITIAL SLIP DETECTING UNIT
231
INITIAL SLIP DIRECTION CALCULATING UNIT
232
INITIAL SLIP AMOUNT CALCULATING UNIT
233
TIP POSITION/POSTURE CALCULATING UNIT
234
GRIPPING FORCE CALCULATING UNIT
235
CONTROL UNIT
213
ARM CONTROL UNIT
241
HAND CONTROL UNIT
242
ARM UNIT
2
HAND PORTION
1
INFORMATION PROCESSING DEVICE
201

FIG. 10

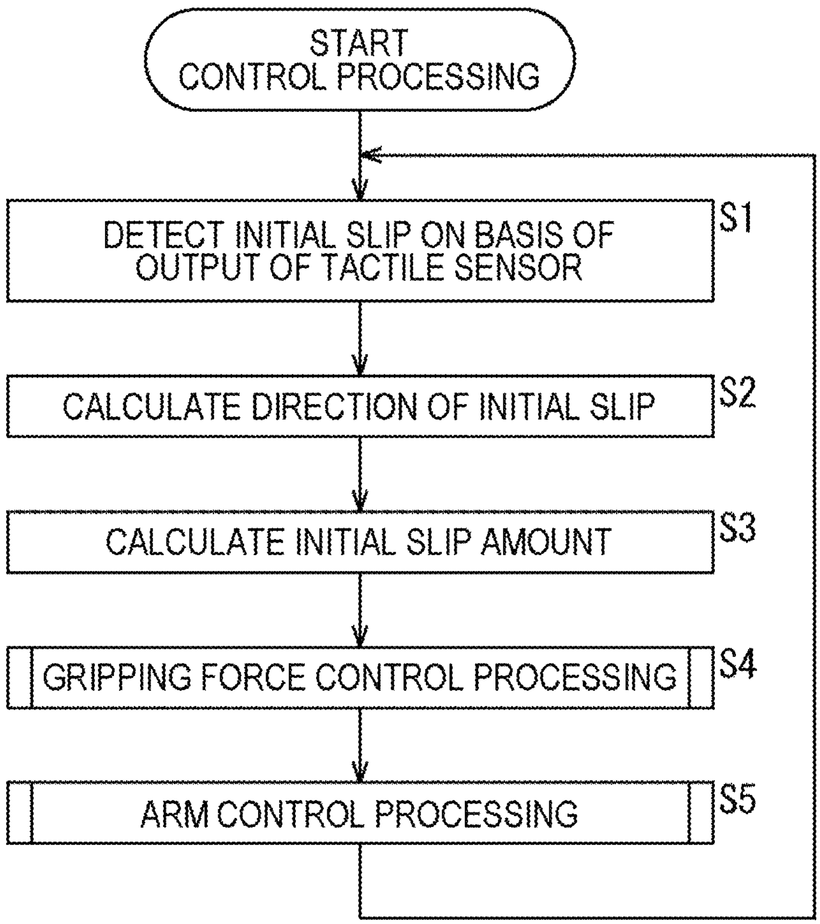

START
CONTROL PROCESSING
DETECT INITIAL SLIP ON BASIS OF
OUTPUT OF TACTILE SENSOR
S1
CALCULATE DIRECTION OF INITIAL SLIP
S2
CALCULATE INITIAL SLIP AMOUNT
S3
GRIPPING FORCE CONTROL PROCESSING
S4
ARM CONTROL PROCESSING
S5

FIG. 11

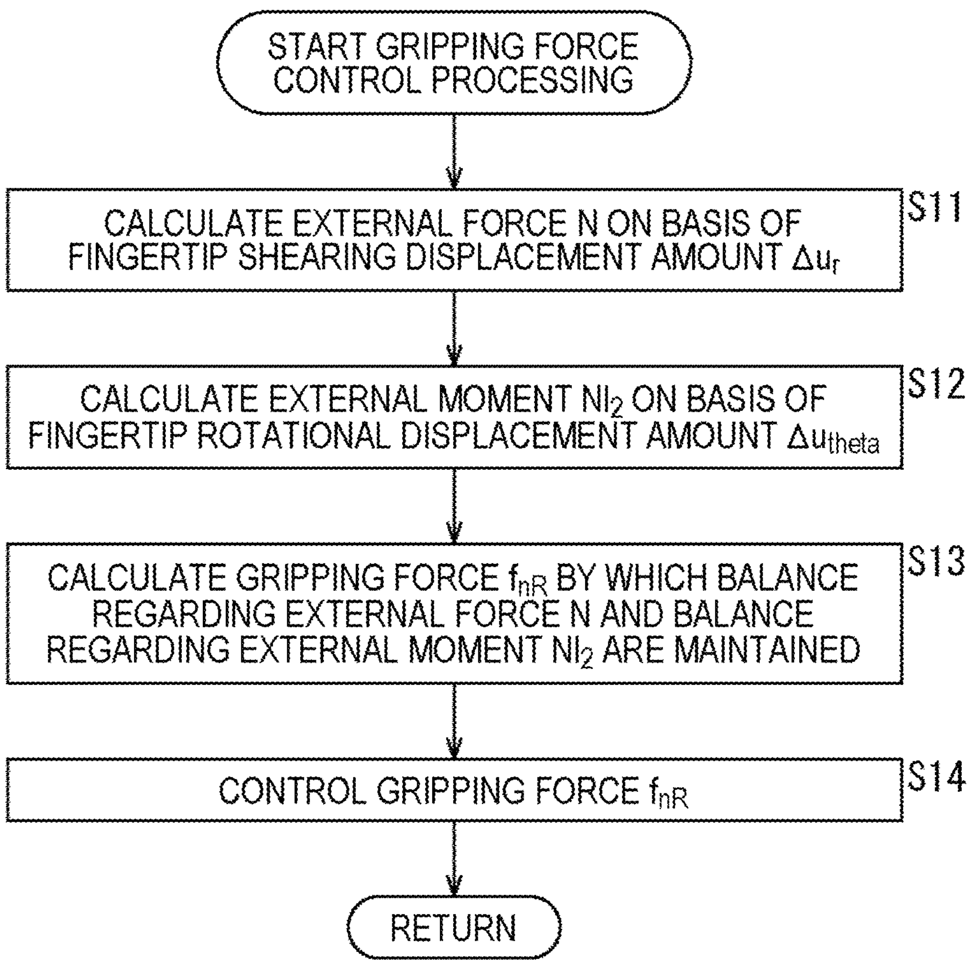
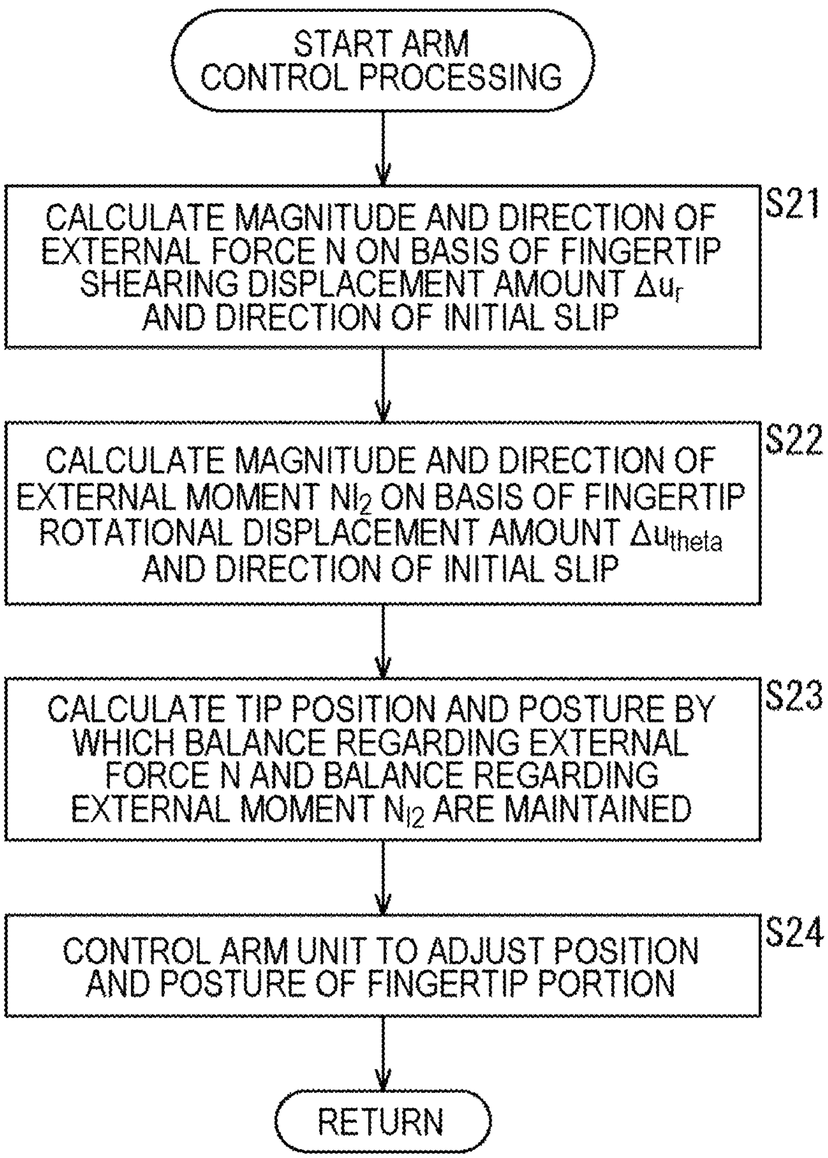

START GRIPPING FORCE CONTROL PROCESSING
CALCULATE EXTERNAL FORCE N ON BASIS OF FINGERTIP SHEARING DISPLACEMENT AMOUNT Δu_r
S11
CALCULATE EXTERNAL MOMENT Nl_2 ON BASIS OF FINGERTIP ROTATIONAL DISPLACEMENT AMOUNT Δu_{theta}
S12
CALCULATE GRIPPING FORCE f_{nR} BY WHICH BALANCE REGARDING EXTERNAL FORCE N AND BALANCE REGARDING EXTERNAL MOMENT Nl_2 ARE MAINTAINED
S13
CONTROL GRIPPING FORCE f_{nR}
S14
RETURN

FIG. 12



START ARM CONTROL PROCESSING
CALCULATE MAGNITUDE AND DIRECTION OF EXTERNAL FORCE N ON BASIS OF FINGERTIP SHEARING DISPLACEMENT AMOUNT Δu_r AND DIRECTION OF INITIAL SLIP
S21
CALCULATE MAGNITUDE AND DIRECTION OF EXTERNAL MOMENT Nl_2 ON BASIS OF FINGERTIP ROTATIONAL DISPLACEMENT AMOUNT Δu_{theta} AND DIRECTION OF INITIAL SLIP
S22
CALCULATE TIP POSITION AND POSTURE BY WHICH BALANCE REGARDING EXTERNAL FORCE N AND BALANCE REGARDING EXTERNAL MOMENT N_{l2} ARE MAINTAINED
S23
CONTROL ARM UNIT TO ADJUST POSITION AND POSTURE OF FINGERTIP PORTION
S24
RETURN

FIG. 13

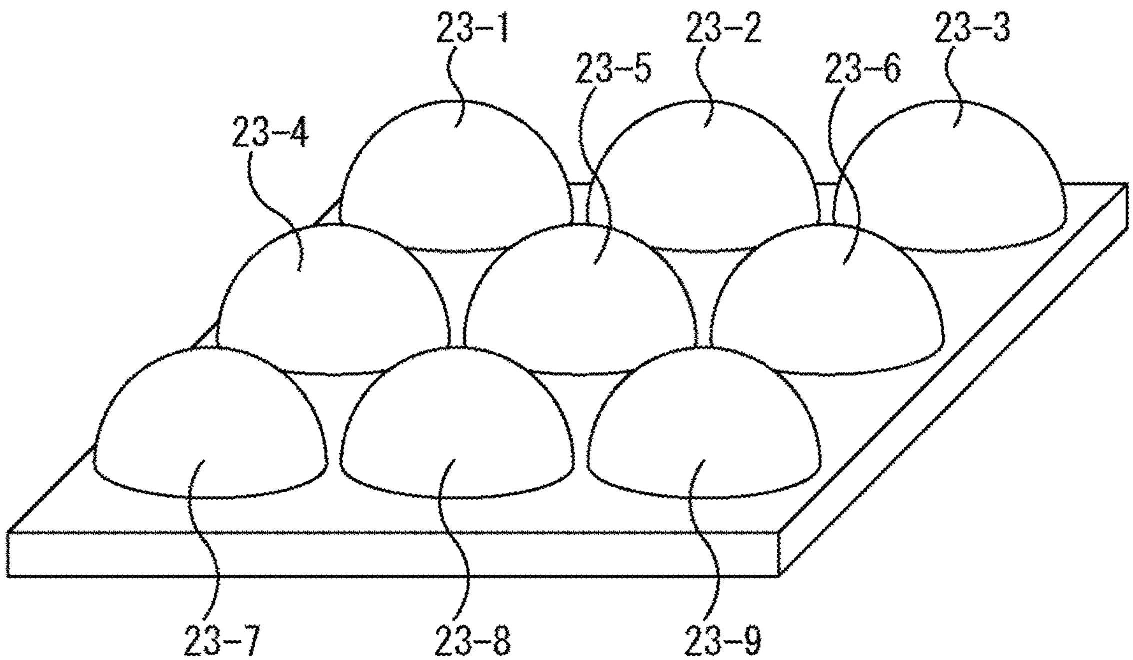


FIG. 14

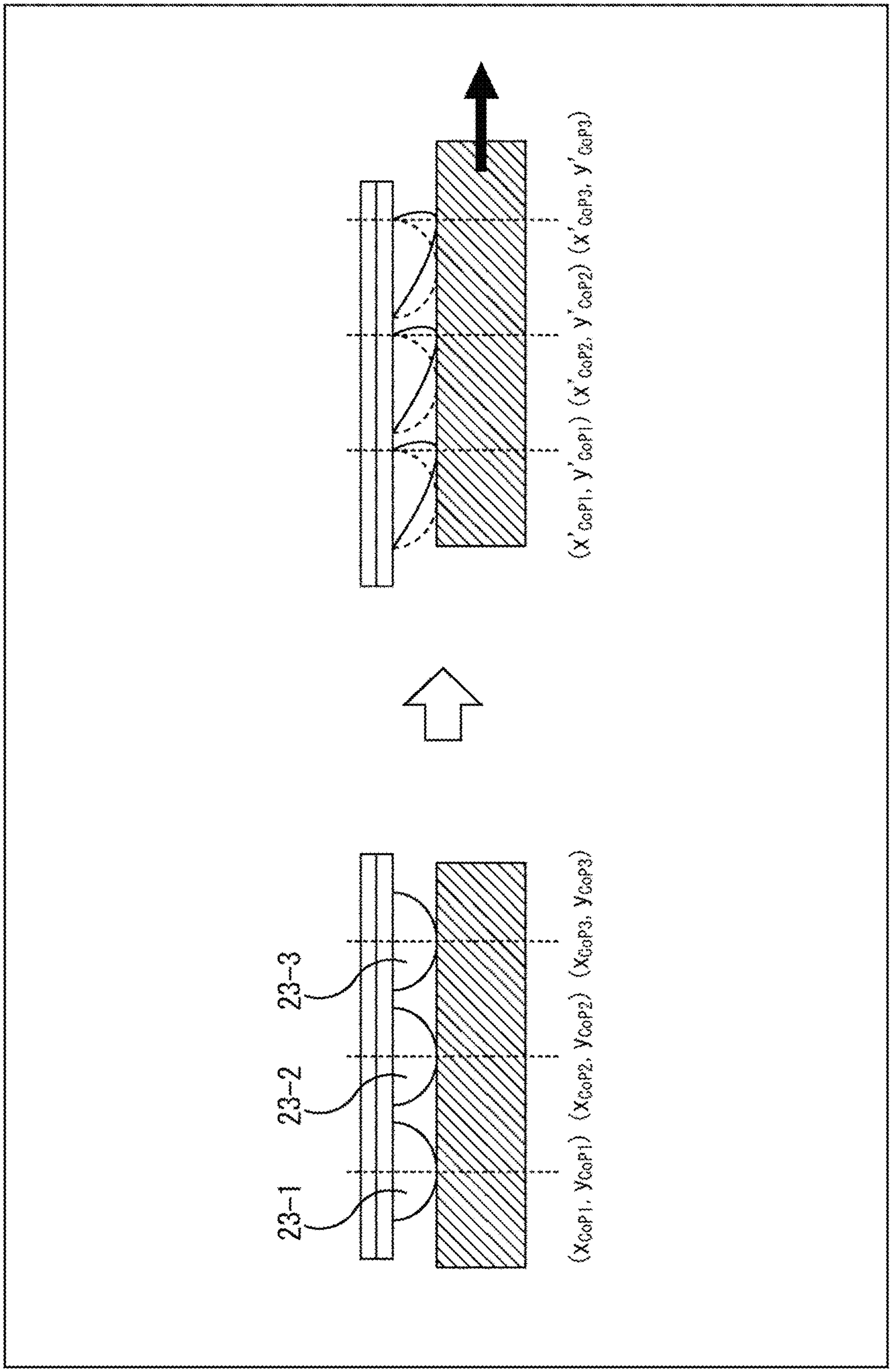

23-1
23-2
23-3
(x_CoP1, y_CoP1) (x_CoP2, y_CoP2) (x_CoP3, y_CoP3)
(x'_CoP1, y'_CoP1) (x'_CoP2, y'_CoP2) (x'_CoP3, y'_CoP3)

FIG. 15

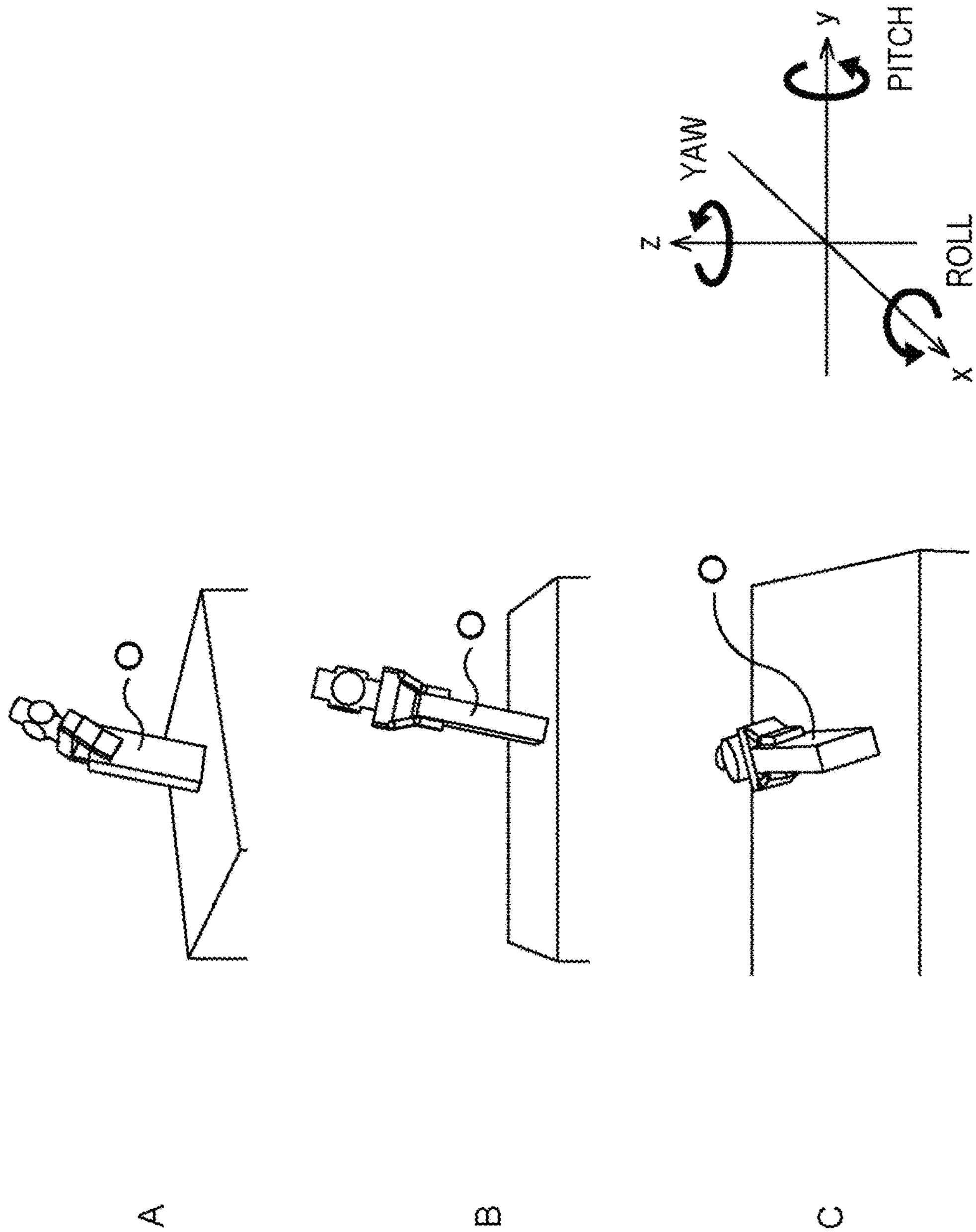


FIG. 16

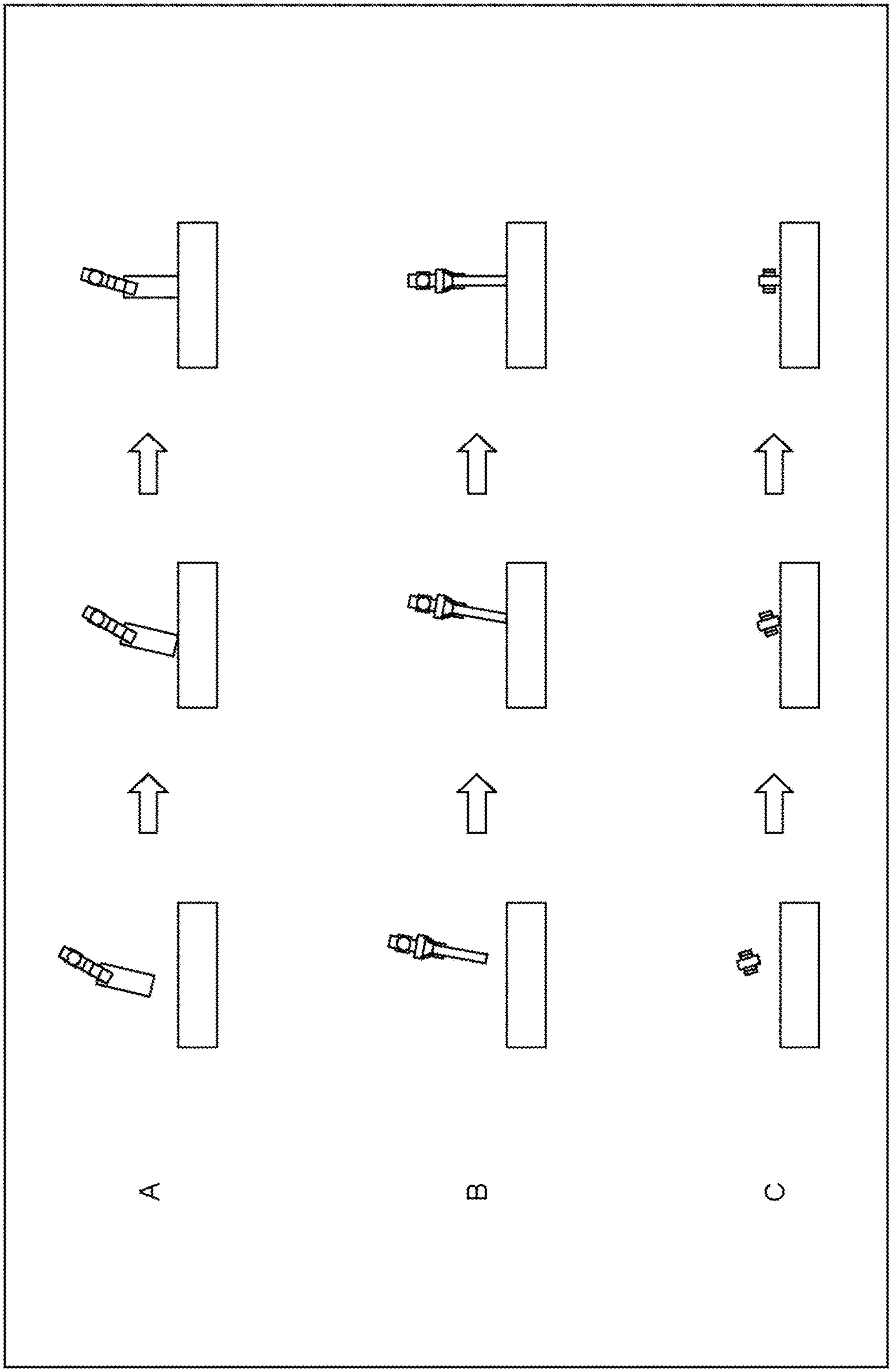
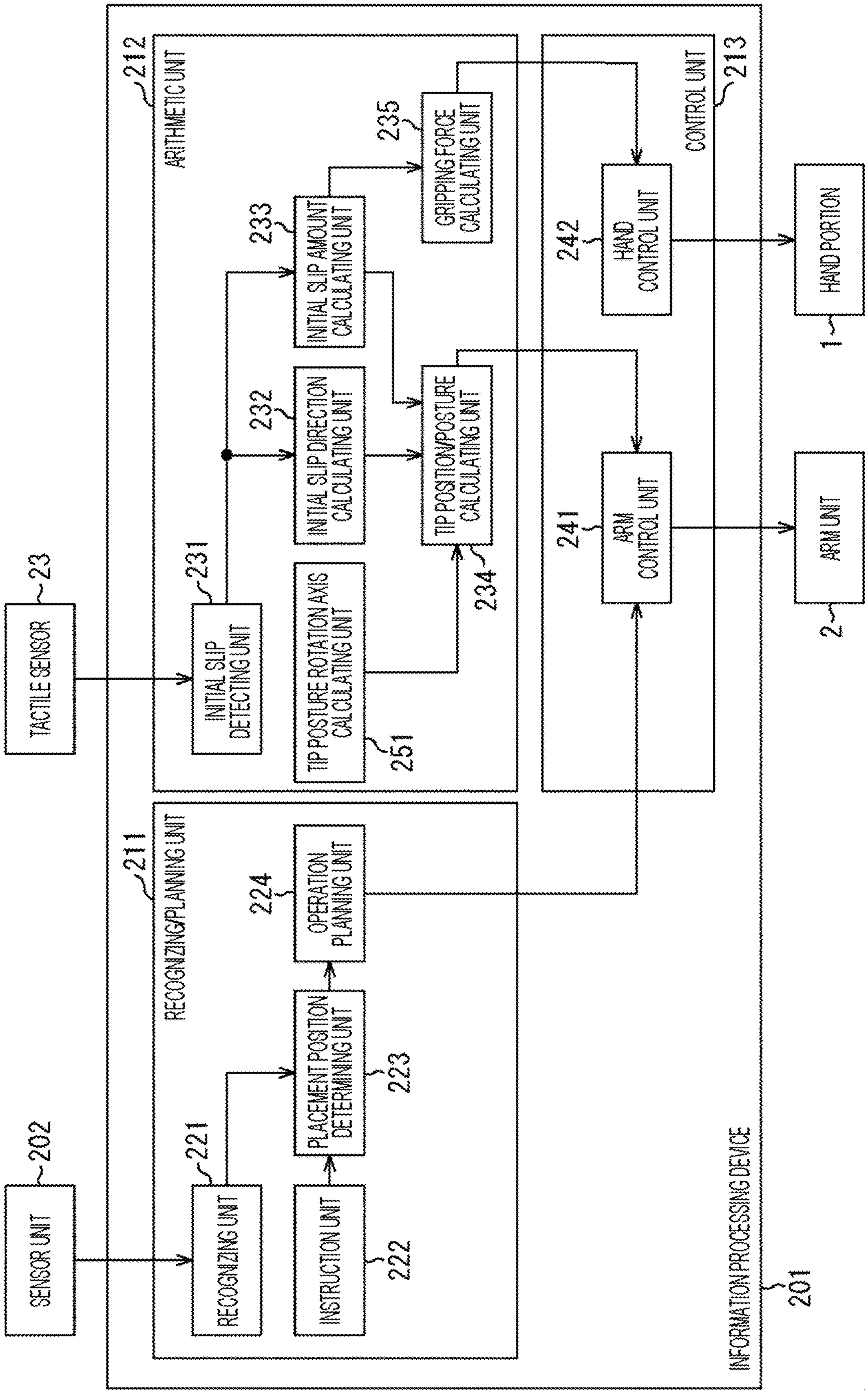
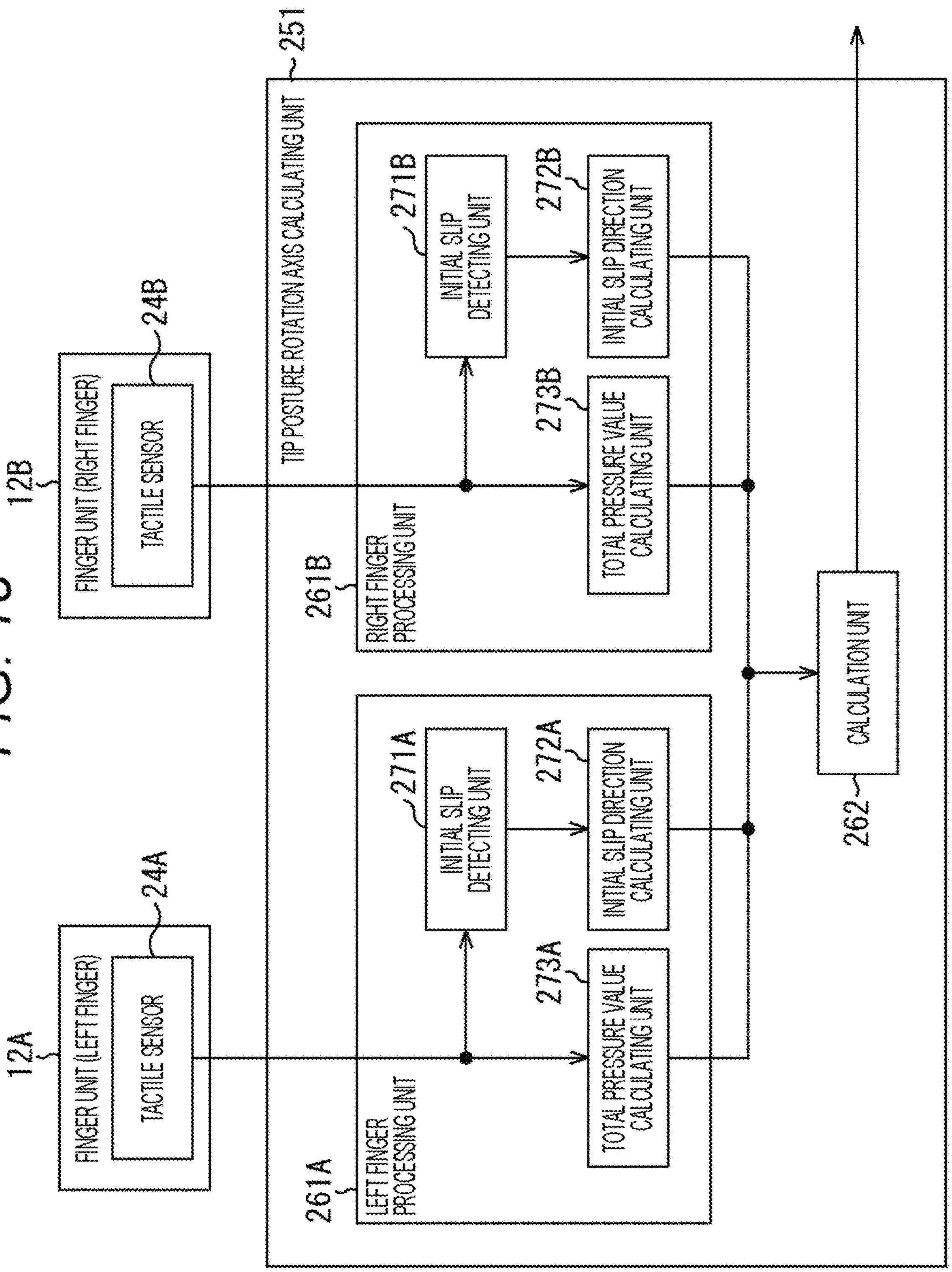


FIG. 17



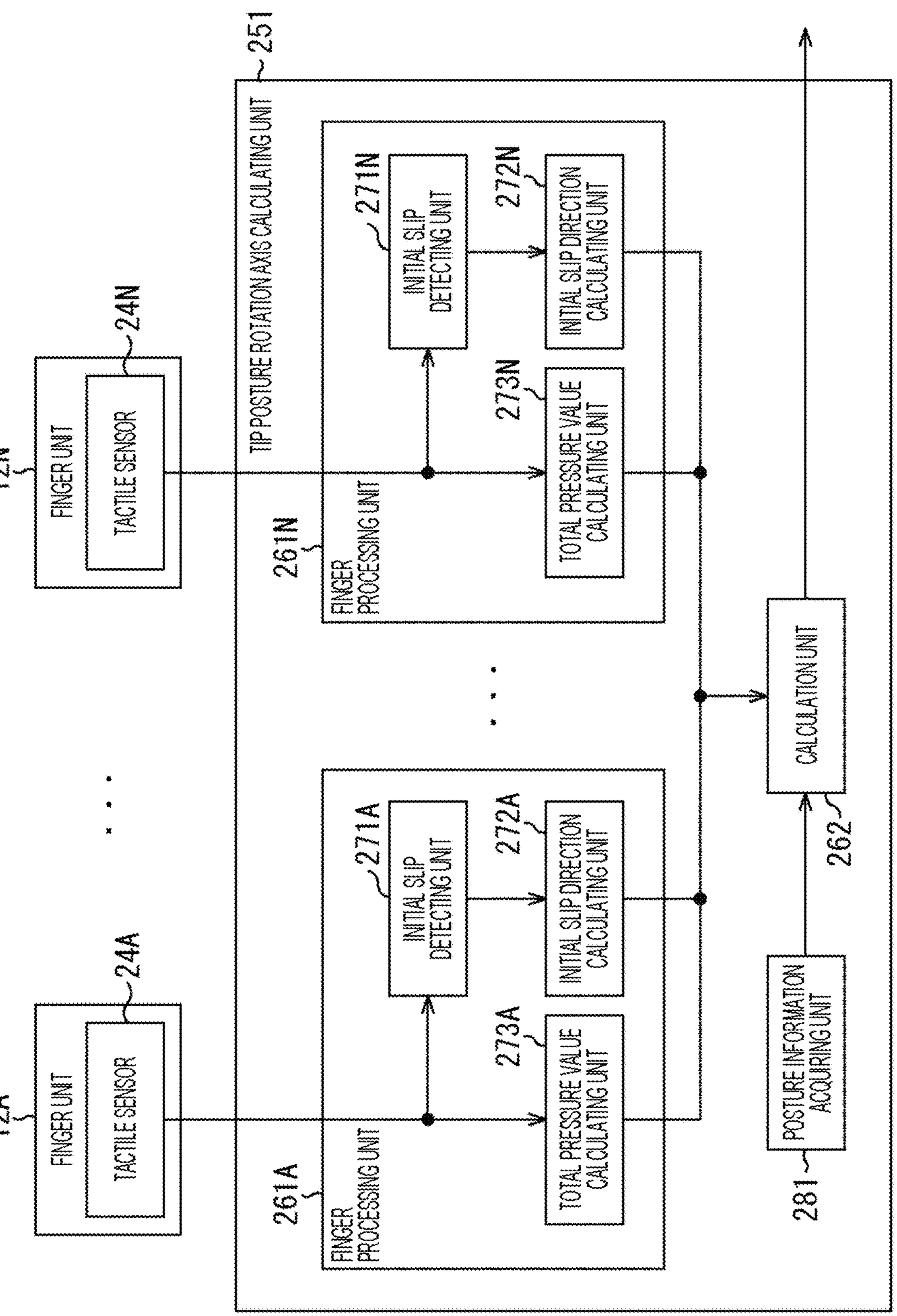
TACTILE SENSOR
23
SENSOR UNIT
202
INFORMATION PROCESSING DEVICE
201
RECOGNIZING/PLANNING UNIT
211
ARITHMETIC UNIT
212
CONTROL UNIT
213
RECOGNIZING UNIT
221
INSTRUCTION UNIT
222
PLACEMENT POSITION DETERMINING UNIT
223
OPERATION PLANNING UNIT
224
INITIAL SLIP DETECTING UNIT
231
INITIAL SLIP DIRECTION CALCULATING UNIT
232
INITIAL SLIP AMOUNT CALCULATING UNIT
233
TIP POSITION/POSTURE CALCULATING UNIT
234
GRIPPING FORCE CALCULATING UNIT
235
TIP POSTURE ROTATION AXIS CALCULATING UNIT
251
ARM CONTROL UNIT
241
HAND CONTROL UNIT
242
ARM UNIT
2
HAND PORTION
1

FIG. 18



12B
FINGER UNIT (RIGHT FINGER)
TACTILE SENSOR
24B
12A
FINGER UNIT (LEFT FINGER)
TACTILE SENSOR
24A
251
TIP POSTURE ROTATION AXIS CALCULATING UNIT
261B
RIGHT FINGER PROCESSING UNIT
271B
INITIAL SLIP DETECTING UNIT
272B
INITIAL SLIP DIRECTION CALCULATING UNIT
273B
TOTAL PRESSURE VALUE CALCULATING UNIT
261A
LEFT FINGER PROCESSING UNIT
271A
INITIAL SLIP DETECTING UNIT
272A
INITIAL SLIP DIRECTION CALCULATING UNIT
273A
TOTAL PRESSURE VALUE CALCULATING UNIT
262
CALCULATION UNIT

FIG. 19



12A
FINGER UNIT
TACTILE SENSOR
24A
12N
FINGER UNIT
TACTILE SENSOR
24N
251
TIP POSTURE ROTATION AXIS CALCULATING UNIT
261A
FINGER PROCESSING UNIT
271A
INITIAL SLIP DETECTING UNIT
272A
INITIAL SLIP DIRECTION CALCULATING UNIT
273A
TOTAL PRESSURE VALUE CALCULATING UNIT
261N
FINGER PROCESSING UNIT
271N
INITIAL SLIP DETECTING UNIT
272N
INITIAL SLIP DIRECTION CALCULATING UNIT
273N
TOTAL PRESSURE VALUE CALCULATING UNIT
262
CALCULATION UNIT
281
POSTURE INFORMATION ACQUIRING UNIT

FIG. 20

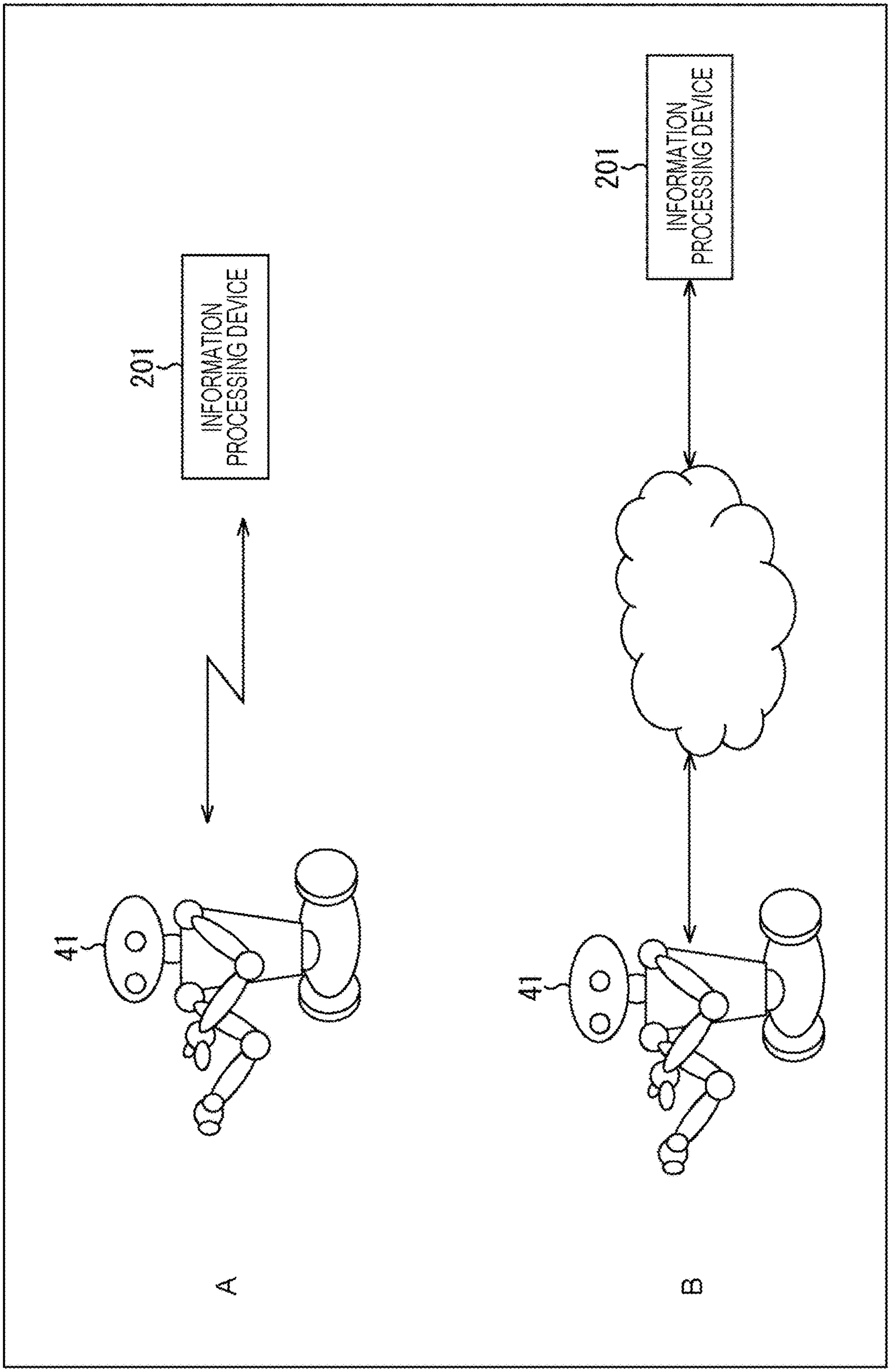
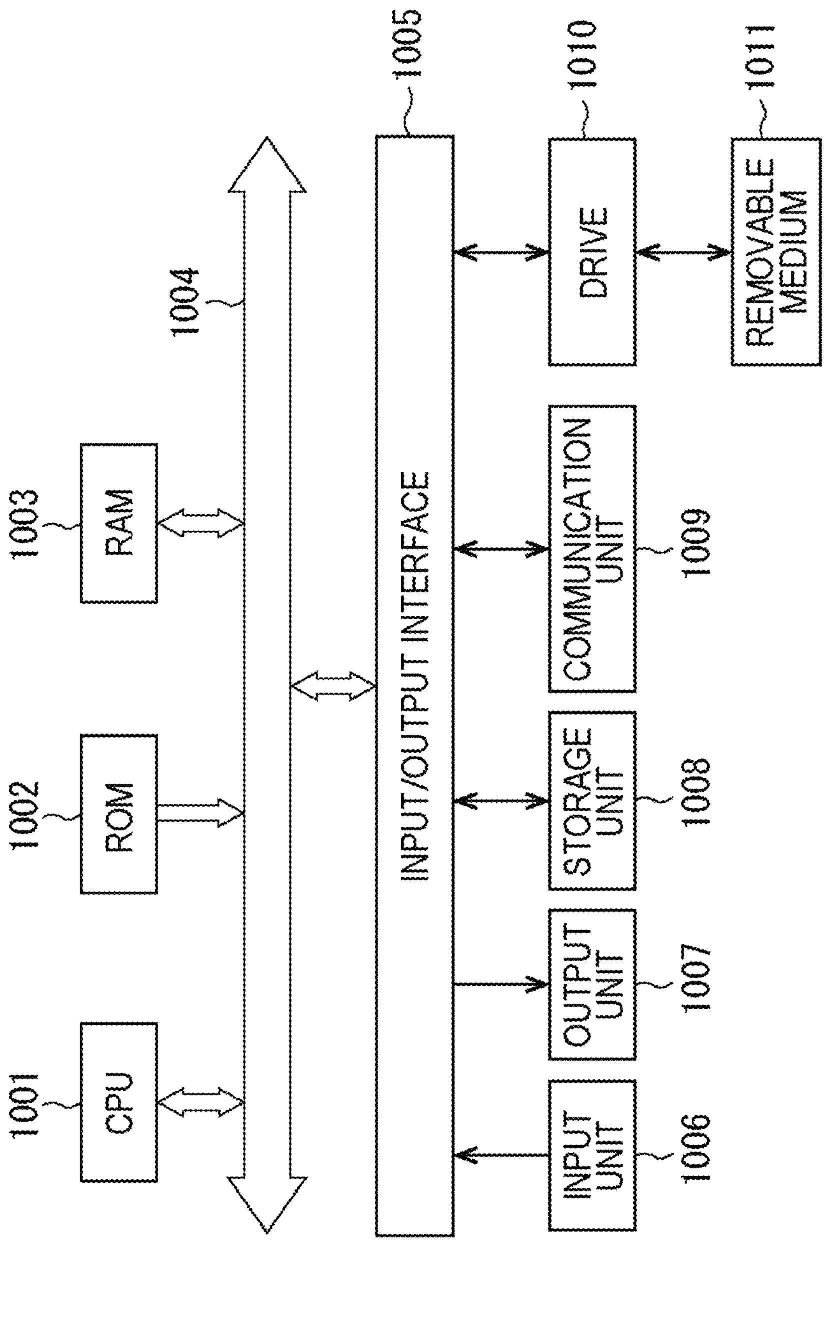

A
41
201
INFORMATION PROCESSING DEVICE
B
41
201
INFORMATION PROCESSING DEVICE

FIG. 21


1001
CPU
1002
ROM
1003
RAM
1004
1005
INPUT/OUTPUT INTERFACE
1006
INPUT UNIT
1007
OUTPUT UNIT
1008
STORAGE UNIT
1009
COMMUNICATION UNIT
1010
DRIVE
1011
REMOVABLE MEDIUM

INFORMATION PROCESSING DEVICE, INFORMATION PROCESSING METHOD, AND PROGRAM

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is based on PCT filing PCT/JP2021/029383, filed Aug. 6, 2021, which claims priority to Japanese Application No. 2020-139481, filed Aug. 20, 2020, the entire contents of each are incorporated herein by reference.

TECHNICAL FIELD

The present technology particularly relates to an information processing device, an information processing method, and a program with which it is possible to place a gripped object more stably.

BACKGROUND ART

Various technologies have been proposed as technologies for gripping and stably placing an object with a robot hand.

For example, Patent Document 1 discloses a technology of transferring a workpiece to the vicinity of a target position, then, dropping the workpiece on a flat surface by reducing a gripping force of a hand portion, and aligning the workpiece with the flat surface. When the workpiece is dropped onto the flat surface, a slip is detected using a slip sensor, and the gripping force is adjusted so that an amount of the slip of the workpiece is equal to or less than a preset threshold.

CITATION LIST

Patent Document

Patent Document 1: Japanese Patent Application Laid-Open No. 2012-206206
Patent Document 2: Japanese Patent Application Laid-Open No. 2009-255191
Patent Document 3: Japanese Patent Application Laid-Open No. 2007-276112

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

In the technology described in Patent Document 1, it is necessary to set a threshold of an amount of slip in advance for each object, and thus, it is difficult to apply the technology to an unknown object. In addition, since the workpiece is dropped with the force of gravity, an excessive impact may be applied to the workpiece.

The present technology has been made in view of such a situation, and an object of the present technology is to place a gripped object more stably.

Solutions to Problems

An information processing device according to one aspect of the present technology includes: a slip detecting unit that detects a slip generated in an object gripped by a finger portion constituting a grip portion; an estimation unit that estimates an external force and an external moment applied to the object on the basis of the slip generated in the object; and an arm control unit that controls an operation of an arm portion on the basis of the estimated external force and external moment to adjust at least one of a position or a posture of the finger portion constituting the grip portion provided in the arm portion.

In one aspect of the present technology, a slip generated in the object being gripped by the finger portion constituting the grip portion is detected, and an external force and an external moment applied to the object are estimated on the basis of the slip generated in the object. In addition, the operation of the arm portion is controlled on the basis of the estimated external force and external moment to adjust at least one of the position or the posture of the finger portion constituting the grip portion provided in the arm portion.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a diagram illustrating an appearance of a robot hand according to an embodiment of the present technology.

FIG. **2** is an enlarged view illustrating a part of a fingertip portion.

FIG. **3** is a diagram illustrating a state of gripping with the fingertip portion.

FIG. **4** is a diagram illustrating an example of an appearance of a robot to which a hand portion is attached.

FIG. **5** is a diagram illustrating a state in which a gripped object is placed.

FIG. **6** is a diagram illustrating a force acting on an object.

FIG. **7** is a diagram illustrating a model for describing the Hertz contact theory.

FIG. **8** is a diagram illustrating an example of a case where an external force acts on the object.

FIG. **9** is a block diagram illustrating a configuration example of an information processing device.

FIG. **10** is a flowchart for describing gripping force control and arm control processing.

FIG. **11** is a flowchart illustrating gripping force control processing performed in step **S4** in FIG. **10**.

FIG. **12** is a flowchart illustrating arm control processing performed in step **S5** in FIG. **10**.

FIG. **13** is a diagram illustrating an arrangement example of a contact portion.

FIG. **14** is a diagram illustrating a change in the state of the contact portion.

FIG. **15** is a diagram illustrating an example of a change in a gripping posture.

FIG. **16** is a diagram illustrating an example of adjustment of the gripping posture.

FIG. **17** is a block diagram illustrating another configuration example of the information processing device.

FIG. **18** is a block diagram illustrating a configuration example of a tip posture rotation axis calculating unit.

FIG. **19** is a block diagram illustrating another configuration example of the tip posture rotation axis calculating unit.

FIG. **20** is a block diagram illustrating a configuration example of a control system.

FIG. **21** is a block diagram illustrating a configuration example of a computer.

MODE FOR CARRYING OUT THE INVENTION

Modes for carrying out the present technology will be described below. The description will be given in the following order.

1. Configuration of robot hand
2. Placement of unknown object

3. Estimation of external force and external moment using slip detection
4. Configuration of information processing device
5. Operation of information processing device
6. Calculation of fingertip rotational displacement amount Δu_{theta}
7. Modification
8. Other examples

Configuration of Robot Hand

FIG. **1** is a diagram illustrating an appearance of a robot hand according to an embodiment of the present technology.

As illustrated in FIG. **1**, a hand portion **1** which is the robot hand according to the embodiment of the present technology is a gripper type grip portion with two fingers. A finger unit **12**A and a finger unit **12**B constituting two fingers are attached to a base **11**. The base **11** functions as a support for supporting the plurality of finger units **12**.

The finger unit **12**A is obtained by connecting a member **21**A and a member **22**A each of which is a plate-shaped member having a predetermined thickness. The member **22**A is mounted on the tip side of the member **21**A attached to the base **11**. The connection portion between the base **11** and the member **21**A and the connection portion between the member **21**A and the member **22**A each have a predetermined range of motion. A contact portion **23**A serving as a contact portion with an object to be gripped is provided inside the member **22**A. The member **22**A and the contact portion **23**A constitute a fingertip portion **31**A.

The finger unit **12**B also has a configuration similar to that of the finger unit **12**A. The member **22**B is mounted on the tip side of the member **21**B attached to the base **11**. The connection portion between the base **11** and the member **21**B and the connection portion between the member **21**B and the member **22**B each have a predetermined range of motion. A contact portion **23**B is provided inside the member **22**B. The member **22**B and the contact portion **23**B constitute a fingertip portion **31**B.

In the following, in a case where it is not necessary to distinguish the finger unit **12**A and the finger unit **12**B, they are collectively referred to as finger unit **12** as appropriate. Other configurations provided in pairs will also be described collectively as appropriate.

FIG. **2** is an enlarged view illustrating a part of a fingertip portion **31**. A of FIG. **2** illustrates a side surface of the fingertip portion **31**, and B of FIG. **2** illustrates a front surface (inner surface) of the fingertip portion **31**.

A tactile sensor **24** is provided below the contact portion **23** as illustrated with a hatch. As the tactile sensor **24**, a pressure distribution sensor capable of detecting pressure at each position of the contact portion **23** is used, for example.

The contact portion **23** includes an elastic material such as rubber, and includes a hemispherical soft deformable layer.

The fingertip portion **31**A and the fingertip portion **31**B have a parallel link mechanism. The fingertip portion **31**A and the fingertip portion **31**B are driven such that the inner surfaces are kept parallel. As illustrated in FIG. **3**, an object O which is an object being gripped is gripped so as to be sandwiched between the contact portion **23**A on the fingertip portion **31**A side and the contact portion **23**B on the fingertip portion **31**B side, the fingertip portions **31**A and **31**B being arranged such that inner surfaces thereof are parallel to each other.

The contact portion **23** includes an elastic material, so that the contact portion **23** in contact with the object O is deformed with force of gravity or the like applied to the object O, as will be described in detail later.

FIG. **4** is a diagram illustrating an example of an appearance of a robot to which the hand portion **1** is attached.

As illustrated in FIG. **4**, a robot **41** to which the hand portion **1** is attached is a robot having a humanoid upper body and a moving mechanism using wheels. A head **52** having a flattened spherical shape is provided on a body **51**. A visual sensor **52**A including an RGB camera or the like is provided on the front part of the head **52**.

Arm portions **2**L and **2**R which are manipulators with multiple degrees of freedom are attached to an upper end of the body **51**. Hand portions **1**L and **1**R which are end effectors are attached at the distal ends of the arm portions **2**L and **2**R, respectively. The hand portion **1**L is the hand portion **1** serving as the left hand of the robot **41**, and the hand portion **1**R is the hand portion **1** serving as the right hand of the robot.

A carriage-shaped mobile unit **53** is provided at a lower end of the body **51**. The robot **41** can move by rotating the wheels provided on the left and right of the mobile unit **53** or changing the direction of the wheels.

As described above, the robot **41** is capable of executing various tasks such as gripping an object by the hand portion **1** and gripping and carrying the object. The arm portions **2**L and **2**R attached to the movable robot **41** are so-called mobile manipulators.

Placement of Unknown Object

In order to grip an unknown object with a robot hand and stably place the unknown object, control of the robot hand in consideration of the following viewpoints is required. The unknown object indicates an object whose characteristics such as a mass, a position of a center of gravity, or a coefficient of friction are unknown.

- In order to place the object without crushing the object or without causing a slip, it is necessary to place the object with an appropriate gripping force in consideration of an external force and an external moment.
- In a case where the gripping state is changed due to rotation or the like caused by deviation of the center of gravity, it is necessary to place the object after adjusting the posture of the object.

FIG. **5** is a diagram illustrating a state in which a gripped object is placed (put).

A case where an oblong rectangular parallelepiped object O gripped with the fingertip portions **31** that hold the vicinity of a base is brought into contact with a floor surface from the bottom surface of the tip as illustrated in the upper diagram of FIG. **5** and is placed on the floor surface as illustrated in the lower diagram of FIG. **5** will be described. The floor surface serves as a placement surface. The arm portion **2** is moved during an operation of placing the object O in order to stably place the object O, by which the position and posture of the hand portion **1** including the fingertip portion **31** are controlled as indicated by an arrow #1.

FIG. **6** is a diagram illustrating a force acting on the object.

The gravity m_g acts on the object O as indicated by an arrow #11. In addition, by bringing the object O into contact with the floor surface, an external force N acts as a normal force from the floor surface at a contact portion between the object O and the floor surface as indicated by an arrow #12.

In the fingertip portion **31**, a shearing force F_R acts as indicated by an arrow #13, and a moment M_R acts as indicated by an arrow #14.

The balance between the force generated by the robot **41** and the force acting on the object O is expressed by Equation (1).

[Equation 1]

$$F_R=mg-N \tag{1}$$

In addition, the balance between the moment generated by the robot **41** and the moment acting on the object O is expressed by Equation (2).

[Equation 2]

$$M_R=mgl_1-Nl_2 \tag{2}$$

In Equation (2), l_1 is a distance from the gripping position to the center of gravity of the object O (distance between perpendicular lines passing through the respective positions). In addition, l_2 is a distance from the gripping position to a position where the normal force acts (distance between perpendicular lines passing through the respective positions). The external moment which is the moment generated by the normal force from the floor surface is expressed as Nl_2.

Considering the plurality of finger units **12** provided in the hand portion **1**, Equation (1) is expressed as Equation (3). In addition, Equation (2) is expressed as Equation (4). In Equations (3) and (4), the subscript i represents each finger.

[Equation 3]

$$\sum_{i=1}^{n} F_{Ri} = \mathrm{mg} - N \tag{3}$$

[Equation 4]

$$\sum_{i=1}^{n} M_{Ri} = \mathrm{mg}\, l_1 - Nl_2 \tag{4}$$

In the robot **41**, a slip generated in the object O is detected using a slip sense achieved by the tactile sensor **24**, and the external force N and the external moment Nl_2 are estimated on the basis of the detection result of the slip.

Estimation of External Force and External Moment Using Slip Detection

FIG. **7** is a diagram illustrating a model for describing the Hertz contact theory.

In FIG. **7**, an elastic sphere **111** corresponds to the contact portion **23** of the hand portion **1**, and a rigid flat plate **110** corresponds to the object O.

The left diagram of FIG. **7** illustrates a state in which the rigid flat plate **110** is in contact with the elastic sphere **111** in the horizontal direction. On the other hand, the right diagram of FIG. **7** illustrates a state in which the normal force f_n is applied to the rigid flat plate **110** and the shearing force f_t is applied in the horizontal direction.

When the shearing force f_t is applied, the elastic sphere **111** is deformed in the direction of the shearing force f_t as illustrated in the right diagram of FIG. **7**. The position of the contact point between the rigid flat plate **110** and the elastic sphere **111** moves from the position before the shearing force f_t is applied by a displacement amount u_r.

The displacement amount ur indicates a displacement amount generated at the fingertip portion **31** of the hand portion **1** in the robot **41**. In the following, the displacement amount of the position generated in the fingertip portion **31** by the application of a force corresponding to the shearing force f_t is referred to as a fingertip shearing displacement amount u_r. In addition, the displacement amount in the rotation direction generated in the fingertip portion **31** is referred to as fingertip rotational displacement amount u_{theta}. When a force corresponding to the shearing force f_t is applied to the fingertip portion **31**, the displacement in the rotational direction also occurs.

The fingertip shearing displacement amount u_r is expressed by Equation (5) according to the Hertz contact theory.

[Equation 5]

$$u_r = \frac{f_t}{G^*\pi}\left(\frac{3Rf_n}{4E^*}\right)^{-\frac{2}{3}} \tag{5}$$

In Equation (5), R is a radius of curvature of the elastic sphere **111**. G* is a composite transverse elastic modulus of the elastic sphere **111** and the rigid flat plate **110**, and E* is a composite longitudinal elastic modulus of the elastic sphere **111** and the rigid flat plate **110**.

Here, the radius of curvature R, the composite transverse elastic modulus G*, and the composite longitudinal elastic modulus E* are physical information of the elastic sphere **111** and the rigid flat plate **110**, and are constants. The fingertip shearing displacement amount u_r depends on the normal force f_n and the shearing force f_t.

Meanwhile, the fingertip rotational displacement amount u_{theta} is expressed by Equation (6).

[Equation 6]

$$u_{theta} = \frac{M}{G^*\pi R^{\frac{5}{3}}}\left(\frac{3f_n}{4E^*}\right)^{-\frac{2}{3}} \tag{6}$$

The fingertip rotational displacement amount u_{theta} depends on the normal force f_n and the moment M.

Next, a case where the external force N acts on the object O while the robot **41** grips the object O with the gripping force f_{nR} will be considered. As described with reference to FIGS. **5** and **6**, when the object O is placed on the floor surface, the external force N acts on the object O as a normal force.

FIG. **8** is a diagram illustrating an example in which the case where the external force N acts on the object O is applied to the model described with reference to FIG. **7**.

As illustrated in FIG. **8**, the normal force f_n in FIG. **7** corresponds to the gripping force f_{nR}. In addition, the shearing force f_t in FIG. **7** corresponds to the external force N. In the state of FIG. **8**, the moment M corresponds to the external moment Nl_2.

The fingertip shearing displacement amount Δu_r which is the fingertip shearing displacement amount when the external force N acts on the object O is expressed as Equation (7) that is obtained by transforming Equation (5). In addition, the fingertip rotational displacement amount Δu_{theta} which is the fingertip rotational displacement amount when the external force N acts on the object O is expressed as Equation (8) that is obtained by transforming Equation (6).

[Equation 7]

$$\Delta u_r = \frac{N}{G^*\pi}\left(\frac{3Rf_{nR}}{4E^*}\right)^{-\frac{2}{3}} \tag{7}$$

[Equation 8]

$$\Delta u_{theta} = \frac{Nl_2}{G^*\pi R^{\frac{5}{3}}}\left(\frac{3f_{nR}}{4E^*}\right)^{-\frac{2}{3}} \tag{8}$$

As expressed in Equation (7), the fingertip shearing displacement amount Δu_r depends on the gripping force f_{nR} and the external force N. Since the gripping force f_{nR} is known in a control unit that controls the gripping force of the hand portion **1**, the external force N can be estimated by observing the fingertip shearing displacement amount Δu_r.

As expressed in Equation (8), the fingertip rotational displacement amount Δu_{theta} depends on the gripping force f_{nR} and the external moment Nl_2. Since the gripping force f_{nR} is known, the external moment Nl_2 can be estimated by observing the fingertip rotational displacement amount Δu_{theta}.

As will be described later, the fingertip shearing displacement amount Δu_r and the fingertip rotational displacement amount Δu_{theta} are observed on the basis of the detection result by the tactile sensor **24** in the robot **41**. Furthermore, the external force N is estimated on the basis of the observation result of the fingertip shearing displacement amount Δu_r, and the external moment Nl_2 is estimated on the basis of the observation result of the fingertip rotational displacement amount Δu_{theta}.

Here, the fingertip shearing displacement amount Δu_r and the fingertip rotational displacement amount Δu_{theta} each correspond to a change (for example, a change per unit time) in the magnitude of slip of the elastic sphere **111** with respect to the rigid flat plate **110**. In other words, the fingertip shearing displacement amount Δu_r and the fingertip rotational displacement amount Δu_{theta} are values indicating a degree of slip of the elastic sphere **111** with respect to the rigid flat plate **110**.

Note that, in the slip illustrated in FIGS. **7** and **8**, the absolute contact position moves while maintaining the relative positional relationship of the contact position between the elastic sphere **111** and the rigid flat plate **110**, and thus, the slip illustrated in FIGS. **7** and **8** is a so-called initial slip.

The slip detected on the basis of the output of the tactile sensor **24** is an initial slip in which a fixed portion (a portion where static friction occurs) and a portion where slip occurs (a portion where dynamic friction occurs) are mixed on the contact surface between the contact portion **23** of the fingertip portion **31** and the gripped object. The external force N and the external moment Nl_2 are estimated using the initial slip.

Configuration of Information Processing Device

FIG. **9** is a block diagram illustrating a configuration example of an information processing device **201**.

The information processing device **201** includes a computer such as a PC. The computer constituting the information processing device **201** is housed in, for example, the body **51**. A CPU of the information processing device **201** executes a predetermined program to implement functional units illustrated in FIG. **9**.

As illustrated in FIG. **9**, a recognizing/planning unit **211**, an arithmetic unit **212**, and a control unit **213** are implemented in the information processing device **201**.

The recognizing/planning unit **211** includes a recognizing unit **221**, an instruction unit **222**, a placement position determining unit **223**, and an operation planning unit **224**. Sensor data representing a detection result by a sensor unit **202** is input to the recognizing unit **221**. The sensor unit **202** includes sensors provided in respective portion of the robot **41** including a visual sensor **52**A. The sensor unit **202** includes various sensors such as an RGB camera, a distance sensor, a ToF sensor, a temperature sensor, a gyro sensor, and an acceleration sensor.

The recognizing unit **221** recognizes the situation of the robot **41** and the surrounding environment of the robot **41** on the basis of the sensor data supplied from the sensor unit **202**. The environment to be recognized by the recognizing unit **221** includes the position and posture of the object being gripped. The recognition result by the recognizing unit **221** is supplied to the placement position determining unit **223**.

The instruction unit **222** determines a task to be executed by the robot **41**, and outputs information regarding the determined task to the placement position determining unit **223**. For example, a task of placing the gripped object is determined.

The placement position determining unit **223** determines the placement position of the gripped object on the basis of the recognition result by the recognizing unit **221** and the task determined by the instruction unit **222**. The placement position determining unit **223** outputs information regarding the placement position of the gripped object to the operation planning unit **224**.

The operation planning unit **224** plans the operation of the arm portion **2** according to the placement position determined by the placement position determining unit **223**, the current position of the arm portion **2**, and the like. The operation planning unit **224** outputs information regarding the operation of the arm portion **2** to an arm control unit **241**.

The arithmetic unit **212** includes an initial slip detecting unit **231**, an initial slip direction calculating unit **232**, an initial slip amount calculating unit **233**, a tip position/posture calculating unit **234**, and a gripping force calculating unit **235**. The initial slip detecting unit **231**, the initial slip direction calculating unit **232**, and the initial slip amount calculating unit **233** are provided for each finger unit **12** so as to correspond to each finger unit **12**.

The initial slip detecting unit **231** detects an initial slip on the basis of a detection result of a pressure distribution by the tactile sensor **24** functioning as a slip sense sensor. For example, the initial slip detecting unit **231** detects the movement of the center of pressure as the initial slip. A center of pressure X_{cop} which is a position of the center of pressure in the X direction is expressed by Equation (9).

[Equation 9]

$$X_{cop} = \frac{\sum_0^{N-1}\{p(x_i)\cdot x_i\}}{\sum_0^{N-1} p(x_i)} \tag{9}$$

In Equation (9), x_i represents a position (X coordinate) of the fingertip portion **31** in the X direction on the inner surface, and $p(x_i)$ represents a pressure at the position x_i. N represents the number of distributions. Similarly, the center of pressure is expressed in relation to the Y direction.

The detection of the initial slip by the initial slip detecting unit **231** is repeatedly performed at a predetermined sampling period. Information regarding the center of pressure at each timing detected by the initial slip detecting unit **231** is supplied to the initial slip direction calculating unit **232** and the initial slip amount calculating unit **233**.

The initial slip direction calculating unit **232** calculates the direction of a change in the center of pressure as the direction of the initial slip on the basis of the detection result by the initial slip detecting unit **231**. The information indicating the direction of the initial slip calculated by the initial slip direction calculating unit **232** is supplied to the tip position/posture calculating unit **234**.

The initial slip amount calculating unit **233** calculates an initial slip amount on the basis of the detection result by the initial slip detecting unit **231**. For example, the initial slip amount calculating unit **233** calculates an amount of change (difference) of the center of pressure as the fingertip shearing displacement amount Δu_r, and calculates an amount of change of the center of pressure in the rotation direction (angular direction) as the fingertip rotational displacement amount Δu_{theta}.

The fingertip rotational displacement amount Δu_{theta} is calculated, for example, on the basis of an amount of relative change of a plurality of centers of pressure detected using a plurality of contact portions **23**. Details of the calculation of the fingertip rotational displacement amount Δu_{theta} will be described later.

Information indicating the initial slip amount including the fingertip shearing displacement amount Δu_r and the fingertip rotational displacement amount Δu_{theta} calculated by the initial slip amount calculating unit **233** is supplied to the tip position/posture calculating unit **234** and the gripping force calculating unit **235**.

The tip position/posture calculating unit **234** applies the fingertip shearing displacement amount Δu_r calculated by the initial slip amount calculating unit **233** to Equation (7) to calculate (estimate) the magnitude of the external force N. The tip position/posture calculating unit **234** estimates the direction of the external force N on the basis of the initial slip direction calculated by the initial slip direction calculating unit **232**.

In addition, the tip position/posture calculating unit **234** applies the fingertip rotational displacement amount Δu_{theta} calculated by the initial slip amount calculating unit **233** to Equation (8) to calculate the magnitude of the external moment Nl_2. The tip position/posture calculating unit **234** estimates the direction of the external moment Nl_2 on the basis of the direction of the initial slip calculated by the initial slip direction calculating unit **232**.

The tip position/posture calculating unit **234** functions as an estimation unit that estimates the magnitude and direction of the external force N and the magnitude and direction of the external moment Nl_2.

The tip position/posture calculating unit **234** calculates the position and posture of the fingertip portion **31** on the basis of the estimated external force N and external moment Nl_2. For example, the tip position/posture calculating unit **234** calculates the position and posture of the fingertip portion **31** by which the balance between the external force N and the force generated by the robot **41** is maintained and the balance between the external moment Nl_2 and the moment generated by the robot **41** is maintained. Information regarding the position and posture of the fingertip portion **31** calculated by the tip position/posture calculating unit **234** is supplied to the arm control unit **241**.

Here, the position and posture of the fingertip portion **31** corresponding to the tip of the robot **41** are controlled. However, the position and posture of the finger unit **12** or the position and posture of the hand portion **1** may be controlled instead of the position and posture of the fingertip portion **31**, or the positions and postures of the finger unit **12** and the hand portion **1** may be controlled together with the position and posture of the fingertip portion **31**.

Similar to the tip position/posture calculating unit **234**, the gripping force calculating unit **235** calculates the magnitude of the external force N and the magnitude of the external moment Nl_2 on the basis of the fingertip shearing displacement amount Δu_r and the fingertip rotational displacement amount Δu_{theta} calculated by the initial slip amount calculating unit **233**.

The gripping force calculating unit **235** calculates the gripping force f_{nR} of the hand portion **1** on the basis of the estimated external force N and external moment Nl_2. For example, the gripping force calculating unit **235** calculates the gripping force f_{nR} of the hand portion **1** by which the balance between the external force N and the force generated by the robot **41** is maintained and the balance between the external moment Nl_2 and the moment generated by the robot **41** is maintained.

The gripping force f_{nR} by which the balance between the external force N and the force generated by the robot **41** is maintained is calculated, for example, so as to cancel the estimated external force N, that is, so as to make the observed fingertip shearing displacement amount Δu_r zero. In addition, the gripping force f_{nR} by which the balance between the external moment Nl_2 and the force generated by the robot **41** is maintained is calculated, for example, so as to cancel the estimated external force Nl_2, that is, so as to make the observed fingertip rotational displacement amount Δu_{theta} zero. Information regarding the gripping force f_{nR} estimated by the gripping force calculating unit **235** is supplied to the hand control unit **242**.

The control unit **213** includes the arm control unit **241** and the hand control unit **242**.

The arm control unit **241** controls the arm portion **2** according to a plan created by the operation planning unit **224**. Under the control of the arm control unit **241**, the arm portion **2** moves to the vicinity of the placement position for the gripped object. In addition, the arm control unit **241** controls the arm portion **2** according to an arm control algorithm.

For example, the arm control unit **241** controls the arm portion **2** such that the fingertip portion **31** has the position and posture calculated by the tip position/posture calculating unit **234**. The position and posture of the fingertip portion **31** is adjusted using the arm control algorithm so as to cancel the initial slip generated by the external force and the external moment, that is, so that the initial slip amount becomes zero. At least one of the position or the posture may be adjusted.

The hand control unit **242** controls the gripping force f_{nR} of the hand portion **1** in accordance with a gripping force control algorithm. The hand control unit **242** controls the hand portion **1** to grip the gripped object with the gripping force f_{nR} calculated by the gripping force calculating unit **235**.

Operation of Information Processing Device

Gripping force control and arm control processing will be described with reference to the flowchart of FIG. **10**.

In step S1, the initial slip detecting unit **231** detects the movement of the center of pressure as the initial slip on the basis of the output of the tactile sensor **24**.

In step S2, the initial slip direction calculating unit **232** calculates the direction of the initial slip on the basis of the direction of movement of the center of pressure.

In step S3, the initial slip amount calculating unit **233** calculates an initial slip amount. For example, an amount of change of the center of pressure is calculated as the fingertip shearing displacement amount Δu_r, and an amount of change of the center of pressure in the rotation direction is calculated as the fingertip rotational displacement amount Δu_{theta}.

In step S4, gripping force control processing is performed. The gripping force f_{nR} of the hand portion **1** is controlled according to the gripping force control algorithm with the gripping force control processing. The gripping force control processing will be described later in detail with reference to the flowchart of FIG. **11**.

In step S5, arm control processing is performed. Due to the arm control processing, the operation of the arm portion **2** is controlled according to the arm control algorithm, and the position and posture of the fingertip portion **31** are adjusted. The arm control processing will be described later in detail with reference to the flowchart of FIG. **12**.

Next, the gripping force control processing performed in step S4 in FIG. **10** will be described with reference to the flowchart in FIG. **11**.

In step S11, the gripping force calculating unit **235** applies the fingertip shearing displacement amount Aur calculated by the initial slip amount calculating unit **233** to Equation (7) to calculate the magnitude of the external force N.

In step S12, the gripping force calculating unit **235** applies the fingertip rotational displacement amount Δu_{theta} calculated by the initial slip amount calculating unit **233** to Equation (8) to calculate the magnitude of the external moment Nl_2.

In step S13, the gripping force calculating unit **235** calculates the gripping force f_{nR} of the hand portion **1** by which the balance between the external force N and the force generated by the robot **41** is maintained and the balance between the external moment Nl_2 and the moment generated by the robot **41** is maintained.

In step S14, the hand control unit **242** controls the hand portion **1** to grip the gripped object with the gripping force f_{nR} calculated by the gripping force calculating unit **235**. Thereafter, the processing returns to step S4 in FIG. **10**, and the subsequent processes are performed.

Next, the arm control processing performed in step S5 in FIG. **10** will be described with reference to the flowchart in FIG. **12**.

In step S21, the tip position/posture calculating unit **234** applies the fingertip shearing displacement amount Δu_r calculated by the initial slip amount calculating unit **233** to Equation (7) to calculate the magnitude of the external force N. In addition, the tip position/posture calculating unit **234** estimates the direction of the external force N on the basis of the initial slip direction calculated by the initial slip direction calculating unit **232**.

In step S22, the tip position/posture calculating unit **234** applies the fingertip rotational displacement amount Δu_{theta} calculated by the initial slip amount calculating unit **233** to Equation (8) to calculate the magnitude of the external moment Nl_2. In addition, the tip position/posture calculating unit **234** calculates the direction of the external moment Nl_2 on the basis of the direction of the initial slip calculated by the initial slip direction calculating unit **232**.

In step S23, the tip position/posture calculating unit **234** calculates the position and posture of the fingertip portion **31** by which the balance between the external force N and the force generated by the robot **41** is maintained and the balance between the external moment Nl_2 and the moment generated by the robot **41** is maintained.

In step S24, the arm control unit **241** controls the arm portion **2** such that the fingertip portion **31** has the position and posture calculated by the tip position/posture calculating unit **234**. Thereafter, the processing returns to step S5 in FIG. **10**, and the subsequent processes are performed.

As described above, the robot **41** can detect a minute change in the external force by using the tactile sensor **24** provided on the fingertip portion **31**. Furthermore, the robot **41** can place the object even in a case where the placement operation is difficult such as a case where the gripped object is soft or a case where the location where the gripped object is to be placed has a soft environment.

The robot **41** can stably place the unknown object by simultaneously performing the gripping force control and the arm control such that the balance between forces and balance between moments are maintained using the information regarding the slip detected by the tactile sensor **24**.

It is possible to prevent the robot **41** from breaking the object due to application of an excessive force to the gripped object or dropping the object due to application of a too small force during the placement operation by the gripping force control performed so that the balance between forces and the balance between moments are maintained.

That is, the robot **41** can more stably place the gripped object.

Calculation of Fingertip Rotational Displacement Amount Δu_{theta}

The fingertip rotational displacement amount Δu_{theta} is expressed by an amount of change of the center of pressure in the rotation direction as described above. For example, the fingertip rotational displacement amount Δu_{theta} is calculated as follows.

FIG. **13** is a diagram illustrating an arrangement example of the contact portion **23**.

As illustrated in FIG. **13**, a plurality of contact portions **23** is arranged on an inner surface of the fingertip portion **31** which is a contact surface with the gripped object. In the example of FIG. **13**, nine contact portions **23** which are contact portions **23-1** to **23-9** are arranged. The tactile sensor **24** is provided below the contact portions **23-1** to **23-9**. A pressure distribution at a position corresponding to each of the contact portions **23-1** to **23-9** is detected by the tactile sensor **24**.

Due to the plurality of contact portions **23** being arranged as described above, a plurality of centers of pressure corresponding to the number of contact portions **23** can be detected. The fingertip rotational displacement amount Δu_{theta} is calculated on the basis of an amount of relative movement of the plurality of centers of pressure.

FIG. **14** is a diagram illustrating a change in the state of the contact portion **23**.

The left diagram of FIG. **14** illustrates a state of the contact portion **23** before an external force acts, and the right diagram of FIG. **14** illustrates a state of the contact portion **23** on which the external force acts. FIG. **14** illustrates states of the contact portions **23-1** to **23-3**. (x_{copi}, y_{copi}) represents the position of the center of pressure of the contact portion **23-*i*** (i=1 to 9) in the X direction and the Y direction before rotation. (x'_{copi}, y'_{copi}) represents the position of the center of pressure of the contact portion **23**-*i* in the X direction and the Y direction after rotation.

The relationship between the centers of pressure before and after rotation and the fingertip rotational displacement amount Δu_{theta} is expressed by Equation (10) using an affine transformation. The fingertip rotational displacement amount Δu_{theta} is expressed by a matrix having three rows and three columns on the left side of Equation (10).

[Equation 10]

$$\begin{pmatrix} \cos(\Delta u_{theta}) & -\sin(\Delta u_{theta}) & \Delta ux \\ \sin(\Delta u_{theta}) & \cos(\Delta u_{theta}) & \Delta uy \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_{CoPi} \\ y_{CoPi} \\ 1 \end{pmatrix} = \begin{pmatrix} x'_{CoPi} \\ y'_{CoPi} \\ 1 \end{pmatrix} \tag{10}$$

For example, focusing on each contact portion **23**, the same number of relationships represented by Equation (10) as the number of contact portions **23** are obtained. The fingertip rotational displacement amount Δu_{theta} is obtained by approximating the fingertip rotational displacement amount Δu_{theta} when each contact portion **23** is focused using least-square method or the like.

Note that, in Equation (10), Δu_x represents an amount of change of the position of the center of pressure in the X direction. Δu_y represents an amount of change of the position of the center of pressure in the Y direction.

Modification

In a Case Where the Gripping Posture Changes

FIG. **15** is a diagram illustrating an example of a change in a gripping posture.

A, B, and C of FIG. **15** illustrate changes in the gripping posture in the directions of a pitch axis, a roll axis, and a yaw axis, respectively. The gripping posture may change as illustrated in FIG. **15** due to the contact with the floor surface.

The robot **41** calculates the initial slip direction and the total pressure value on the basis of the detection results of the tactile sensors **24** provided at the fingertip portions **31** of the finger unit **12**A serving as the left finger and the finger unit **12**B serving as the right finger. The total pressure value indicates a total value of pressures detected at each position of the tactile sensor **24**.

In addition, the rotation axis of the inclination of the gripped object with respect to the floor surface (the rotation axis of the inclination of the gripping posture of the fingertip portion **31**) is calculated on the basis of the relationship between the initial slip direction and the total pressure value.

The arm portion **2** is controlled so as to cancel the inclination of the gripped object with respect to the floor surface and the posture of the fingertip portion **31** is adjusted, whereby the object O can be placed with the posture of the object O being adjusted.

FIG. **16** is a diagram illustrating an example of adjustment of the gripping posture.

In a case where the gripped object is inclined in the pitch axis direction, the posture of the object O is adjusted by adjusting the posture of the fingertip portion **31** in the pitch axis direction as illustrated in A of FIG. **16**. Similarly, in a case where the gripped object is inclined in the roll axis direction and the yaw axis direction, the posture of the object O is adjusted by adjusting the posture of the fingertip portion **31** in the roll axis direction and the yaw axis direction as illustrated in B and C of FIG. **16**.

FIG. **17** is a block diagram illustrating another configuration example of the information processing device **201**.

In FIG. **17**, the same components as those described with reference to FIG. **9** are denoted by the same reference signs. The overlapping description will be omitted as appropriate. The configuration of the information processing device **201** illustrated in FIG. **17** is the same as the configuration described with reference to FIG. **9** except that a tip posture rotation axis calculating unit **251** is additionally provided.

The tip posture rotation axis calculating unit **251** calculates the rotation axis of the inclination of the posture of the fingertip portion **31**, and outputs information indicating the rotation axis of the inclination to the tip position/posture calculating unit **234**.

The tip position/posture calculating unit **234** calculates the position and posture of the fingertip portion **31** so as to cancel the change in position and posture due to the initial slip in consideration of the rotation axis of the inclination calculated by the tip posture rotation axis calculating unit **251**.

The arm control unit **241** controls the arm portion **2** such that the fingertip portion **31** has the position and posture calculated by the tip position/posture calculating unit **234**. The arm portion **2** is controlled such that the position and posture of the fingertip portion **31** are adjusted in the direction of the rotation axis calculated by the tip posture rotation axis calculating unit **251**.

FIG. **18** is a block diagram illustrating a configuration example of the tip posture rotation axis calculating unit **251**.

As illustrated in FIG. **18**, the tip posture rotation axis calculating unit **251** includes a left finger processing unit **261**A, a right finger processing unit **261**B, and a calculation unit **262**.

The left finger processing unit **261**A includes an initial slip detecting unit **271**A, an initial slip direction calculating unit **272**A, and a total pressure value calculating unit **273**A. Sensor data representing the pressure distribution detected by the tactile sensor **24**A provided in the finger unit **12**A serving as the left finger is supplied to the initial slip detecting unit **271**A and the total pressure value calculating unit **273**A.

The initial slip detecting unit **271**A detects the initial slip by calculating an amount of movement of the center of pressure on the basis of the detection result of the pressure distribution by the tactile sensor **24**A. The detection result by the initial slip detecting unit **271**A is supplied to the initial slip direction calculating unit **272**A.

The initial slip direction calculating unit **272**A calculates the direction of the change in the center of pressure as the direction of the initial slip on the basis of the detection result by the initial slip detecting unit **271**A, and outputs information indicating the direction of the initial slip to the calculation unit **262**.

The total pressure value calculating unit **273**A calculates the total of the pressures at the respective positions by the tactile sensor **24**A on the basis of the detection result of the pressure distribution by the tactile sensor **24**A, and outputs information indicating the total value of the pressures to the calculation unit **262**.

On the other hand, the right finger processing unit **261**B includes an initial slip detecting unit **271**B, an initial slip direction calculating unit **272**B, and a total pressure value calculating unit **273**B. The right finger processing unit **261**B performs processing similar to the processing performed in the left finger processing unit **261**A on the basis of sensor data indicating a pressure distribution detected by the tactile sensor **24**B provided in the finger unit **12**B serving as the right finger.

That is, the initial slip detecting unit **271**B detects the initial slip by calculating an amount of movement of the center of pressure on the basis of the detection result of the pressure distribution by the tactile sensor **24**B. The detection result by the initial slip detecting unit **271**B is supplied to the initial slip direction calculating unit **272**B.

The initial slip direction calculating unit **272**B calculates the direction of the change in the center of pressure as the direction of the initial slip on the basis of the detection result by the initial slip detecting unit **271**B, and outputs information indicating the direction of the initial slip to the calculation unit **262**.

The total pressure value calculating unit **273**B calculates the total of the pressures at the respective positions by the tactile sensor **24**B on the basis of the detection result of the pressure distribution by the tactile sensor **24**B, and outputs information indicating the total value of the pressures to the calculation unit **262**.

The initial slip detecting unit **271**A and the initial slip detecting unit **271**B can be implemented by the initial slip detecting unit **231** in FIG. **17**. In addition, the initial slip direction calculating unit **272**A and the initial slip direction calculating unit **272**B can be implemented by the initial slip direction calculating unit **232** in FIG. **17**.

The calculation unit **262** calculates the rotation axis of the inclination of the posture of the fingertip portion **31** on the basis of the difference between the total value of the pressures calculated by the total pressure value calculating unit **273**A and the total value of the pressures calculated by the total pressure value calculating unit **273**B.

When the rotation axis is calculated, the initial slip directions calculated by the initial slip direction calculating unit **272**A and the initial slip direction calculating unit **272**B are also considered. By considering the initial slip directions, the direction of the rotational force generated by the gripped object with respect to the fingertip portion **31** due to the contact with the floor surface, that is, the rotation axis, is calculated. Information indicating the rotation axis of the inclination of the posture of the fingertip portion **31** calculated by the calculation unit **262** is output to the tip position/posture calculating unit **234**.

In this manner, the rotation axis of the inclination of the posture of the fingertip portion **31** is calculated, and the arm control is performed so that the inclination of the posture is canceled and the balance regarding forces and the balance regarding moments are maintained as described above. Even in a case where the gripping state is changed by rotation due to deviation in gravity center or the like, the robot **41** can adjust the posture of the object and place the object.

Note that the arm control based on the rotation axis of the inclination of the posture of the fingertip portion **31** can be applied not only to a task of placing the gripped object but also to other tasks such as a task of erasing characters written on a whiteboard using a cleaner.

In a Case of Multiple Fingers

In a case where the hand portion **1** has multiple finger units such as three or more finger units, posture information of each finger unit may be used to calculate the rotation axis of the inclination of the posture of the fingertip portion **31**.

FIG. **19** is a block diagram illustrating another configuration example of the tip posture rotation axis calculating unit **251**.

The configuration of the tip posture rotation axis calculating unit **251** illustrated in FIG. **19** is the same as the configuration described with reference to FIG. **18** except that the same number of finger processing units **261** as the finger units **12** are provided, and that a posture information acquiring unit **281** is additionally provided.

The posture information acquiring unit **281** calculates the posture of each finger on the basis of an output of an encoder provided at a joint or the like that is a movable part of each finger, and outputs information indicating the posture of each finger to the calculation unit **262**. The encoder provided at a joint or the like of each finger outputs information indicating an amount of movement of the joint.

The calculation unit **262** calculates the rotation axis of the inclination of the gripped object with respect to the floor surface by considering the posture information of each finger in addition to the relationship between the initial slip direction and the total pressure value calculated on the basis of the detection result of the tactile sensor **24** of each finger. Information indicating the rotation axis of the inclination of the posture of the fingertip portion **31** calculated by the calculation unit **262** is output to the tip position/posture calculating unit **234**.

By calculating the rotation axis of the inclination of the gripped object in consideration of the posture information of each finger, it is possible to improve the accuracy of the calculation of the rotation axis as compared with the case of calculating the rotation axis of the inclination of the gripped object only on the basis of the relationship between the initial slip direction and the total pressure value.

Other Examples

Examples of Sensor

Although the initial slip is detected on the basis of the pressure distribution detected by the pressure distribution sensor, the initial slip may be detected using an optical sensor such as an RGB camera or a ToF sensor together with the pressure distribution sensor. In a case where the optical sensor is used together, the shift of each position of the contact portion **23** which is an elastic body is measured by the optical sensor, for example.

The initial slip may be detected using a force sensor together with the pressure distribution sensor. In a case where the force sensor is used together, it is detected that the initial slip has occurred when, for example, the magnitude of the force applied to the contact portion **23** reaches a magnitude set in advance as the magnitude of the force at the time of occurrence of the initial slip.

When the arm portion **2** is controlled using the arm control algorithm, operation plan information indicating the operation of the arm portion **2** may be used.

System Configuration

FIG. **20** is a diagram illustrating a configuration example of a control system.

The control system illustrated in FIG. **20** is configured by providing the information processing device **201** as a device outside the robot **41**. In this manner, the information processing device **201** may be provided outside the housing of the robot **41**.

Wireless communication using a wireless LAN, wireless communication using a mobile communication system, or the like is performed between the robot **41** and the information processing device **201** in FIG. **20**.

Various types of information such as information indicating a state of the robot **41** and information indicating a detection result of sensors are transmitted from the robot **41** to the information processing device **201**. Information for controlling the operation of the robot **41** and the like are transmitted from the information processing device **201** to the robot **41**.

The robot **41** and the information processing device **201** may be directly connected as illustrated in A of FIG. **20**, or may be connected via a network such as the Internet as illustrated in B of FIG. **20**. The operations of a plurality of robots **41** may be controlled by one information processing device **201**.

Computer

The series of processing described above can be executed by hardware or by software. In a case where the series of processing is executed by software, a program constituting the software is installed from a program recording medium to a computer incorporated in dedicated hardware, a general-purpose personal computer, or the like.

FIG. **21** is a block diagram illustrating a configuration example of the hardware of a computer that executes the abovementioned series of processing programmatically.

A central processing unit (CPU) **1001**, a read only memory (ROM) **1002**, and a random access memory (RAM) **1003** are connected to each other by a bus **1004**.

An input/output interface **1005** is further connected to the bus **1004**. An input unit **1006** including a keyboard, a mouse, and the like, and an output unit **1007** including a display, a speaker, and the like are connected to the input/output interface **1005**. Furthermore, a storage unit **1008** including a hard disk, a nonvolatile memory, and the like, a communication unit **1009** including a network interface and the like, and a drive **1010** that drives a removable medium **1011** are connected to the input/output interface **1005**.

In the computer configured as described above, the CPU **1001** loads the program stored in, for example, the storage unit **1008** into the RAM **1003** via the input/output interface **1005** and the bus **1004**, and executes the program, whereby the series of processing described above is performed.

The program executed by the CPU **1001** is provided, for example, by being recorded in the removable medium **1011** or via a wired or wireless transmission medium such as a local area network, the Internet, or digital broadcasting, and is installed in the storage unit **1008**.

Note that the program executed by the computer may be a program in which processes are carried out in a time series in the order described in this specification or may be a program in which processes are carried out in parallel or at necessary timings, such as when the processes are called.

In the present specification, a "system" means a set of a plurality of components (devices, modules (parts), etc.), and all components need not be necessarily in the same housing. Therefore, a plurality of devices housed in separate housings and connected via a network, and a single device in which a plurality of modules is housed in one housing are regarded as a system.

It should be noted that the effects described in the present specification are merely illustrative and not restrictive, and may have additional effects.

It should be noted that embodiments of the present technology are not limited to the abovementioned embodiment, and various modifications are possible without departing from the gist of the present technology.

For example, the present technology can employ, for example, a configuration of cloud computing in which one function is shared by a plurality of devices via a network and processed in cooperation with each other.

Further, steps described in the above-described flowcharts may be executed by a single device or shared and executed by a plurality of devices.

Further, in a case where multiple processes are included in one step, the multiple processes included in the one step may be executed by a single device or may be shared and executed by a plurality of devices.

Example of Combination of Configurations

It is to be noted that the present technology may also have the following configurations.

(1)

An information processing device including:

a slip detecting unit that detects a slip generated in an object gripped by a finger portion constituting a grip portion;

an estimation unit that estimates an external force and an external moment applied to the object on the basis of the slip generated in the object; and

an arm control unit that controls an operation of an arm portion on the basis of the estimated external force and external moment to adjust at least one of a position or a posture of the finger portion constituting the grip portion provided in the arm portion.

(2)

The information processing device according to (1), in which

the arm control unit controls the arm portion such that a balance between the estimated external force and a force generated in the object by the operation of the arm portion is maintained, and a balance between the estimated external moment and a moment generated in the object by the operation of the arm portion is maintained.

(3)

The information processing device according to (1) or (2), further including

a gripping force control unit that controls a gripping force of the grip portion on the basis of the estimated external force and external moment.

(4)

The information processing device according to (3), in which

the gripping force control unit controls the gripping force such that a balance between the estimated external force and a force generated in the object by gripping by the grip portion is maintained, and a balance between the estimated external moment and a moment generated in the object by gripping by the grip portion is maintained.

(5)

The information processing device according to any one of (1) to (4), in which

the finger portion includes:

an elastic body that comes into contact with the object when the object is gripped; and

a pressure distribution sensor that detects a distribution of pressure applied to the elastic body, and

the slip detecting unit detects an initial slip in which a fixed portion and a slip portion are mixed between the object and the elastic body on the basis of a detection result of the pressure distribution sensor.

(6)

The information processing device according to (5), in which

the estimation unit estimates directions and amounts of the external force and the external moment applied to the object on the basis of a direction and an amount of the initial slip.

(7)

The information processing device according to (6), in which

the slip detecting unit detects the initial slip on the basis of movement of a center of pressure.

(8)

The information processing device according to (7), further including:

an initial slip direction calculating unit that calculates a direction of the initial slip on the basis of a direction of movement of the center of pressure; and

an initial slip amount calculating unit that calculates an amount of the initial slip on the basis of the amount of movement of the center of pressure.

(9)

The information processing device according to any one of (1) to (8), in which

the slip detecting unit detects a slip generated in the object by a drag applied from a placement surface when the object is placed.

(10)

The information processing device according to any one of (5) to (9), in which

the slip detecting unit detects the initial slip on the basis of a deviation of each position of the elastic body detected by an optical sensor or on the basis of a magnitude of a force applied to the elastic body detected by a force sensor.

(11)

The information processing device according to any one of (5) to (10), in which

the grip portion is provided with a plurality of the finger portions, and

the slip detecting unit detects the initial slip at each of the finger portions on the basis of a detection result of the pressure distribution sensor.

(12)

The information processing device according to (11), further including

a calculation unit that calculates an inclination of the finger portion gripping the object on the basis of a direction of the initial slip and a force detected by the pressure distribution sensor of each of the finger portions, in which

the arm control unit controls an operation of the arm portion on the basis of the calculated inclination.

(13)

The information processing device according to (12), in which

the calculation unit calculates the inclination of the finger portion on the basis of posture information indicating an amount of movement of a movable part of each of the finger portions.

(14)

An information processing method performed by an information processing device, the method including:

detecting a slip generated in an object gripped by a finger portion constituting a grip portion;

estimating an external force and an external moment applied to the object on the basis of the slip generated in the object; and

controlling an operation of an arm portion on the basis of the estimated external force and external moment to adjust at least one of a position or a posture of the finger portion constituting the grip portion provided in the arm portion.

(15)

A program causing a computer to execute:

detecting a slip generated in an object gripped by a finger portion constituting a grip portion;

estimating an external force and an external moment applied to the object on the basis of the slip generated in the object; and

controlling an operation of an arm portion on the basis of the estimated external force and external moment to adjust at least one of a position or a posture of the finger portion constituting the grip portion provided in the arm portion.

REFERENCE SIGNS LIST

1 Hand portion
2L, **2**R Arm portion
11 Base
12A, **12**B Finger unit
23A, **23**B Contact portion
24A, **24**B Tactile sensor
31A, **31**B Fingertip portion
41 Robot
201 Information processing device
202 Sensor unit
211 Recognizing/planning unit
212 Arithmetic unit
213 Control unit
221 Recognizing unit
222 Instruction unit
223 Placement position determining unit
224 Operation planning unit
231 Initial slip detecting unit
232 Initial slip direction calculating unit
233 Initial slip amount calculating unit
234 Tip position/posture calculating unit
235 Gripping force calculating unit
241 Arm control unit
242 Hand control unit
251 Tip posture rotation axis calculating unit
261A Left finger processing unit
261B Right finger processing unit
262 Calculation unit
271A, **271**B Initial slip detecting unit
272A, **272**B Initial slip direction calculating unit
273A, **273**B Total pressure value calculating unit
281 Posture information acquiring unit

The invention claimed is:

1. An information processing device comprising:

circuitry including a CPU that is configured by execution of computer readable instructions to

detect a slip generated in an object gripped by a finger portion constituting a grip portion that is provided on an arm portion;

estimate an external force and an external moment applied to the object on a basis of the slip generated in the object; and

control an operation of the arm portion on a basis of the external force and the external moment to adjust at least one of a position and a posture of the finger portion constituting the grip portion, wherein

the finger portion includes an elastic body that comes into contact with the object when the object is gripped, and a pressure distribution sensor that detects a distribution of pressure applied to the elastic body, and

the circuitry is further configured to

detect an initial slip in which a fixed portion and a slip portion are mixed between the object and the elastic body on a basis of a detection result of the pressure distribution sensor, and

estimate directions and amounts of the external force and the external moment applied to the object on a basis of a direction and an amount of the initial slip.

2. The information processing device according to claim **1**, wherein

the circuitry is further configured to control the arm portion such that a balance between the external force and a force generated on the object by the operation of the arm portion is maintained, and a balance between the external moment and a moment generated on the object by the operation of the arm portion is maintained.

3. The information processing device according to claim **1**, wherein

the circuitry is further configured to control a gripping force of the grip portion on a basis of the external force and the external moment.

4. The information processing device according to claim **3**, wherein

the circuitry is further configured to control the gripping force such that a balance between the external force and a force generated on the object by gripping by the grip portion is maintained, and a balance between the external moment and a moment generated on the object by gripping by the grip portion is maintained.

5. The information processing device according to claim **1**, wherein

the circuitry is further configured to detect a slip generated in the object by a drag applied from a placement surface on which the object is placed.

6. The information processing device according to claim **1**, wherein

the circuitry is further configured to detect the initial slip on a basis of movement of a center of pressure.

7. The information processing device according to claim **6**, wherein

the circuitry is further configured to calculate a direction of the initial slip on a basis of a direction of movement of the center of pressure and an amount of the initial slip on a basis of an amount of the movement of the center of pressure.

8. The information processing device according to claim **1**, wherein

the circuitry is further configured to detect the initial slip on a basis of a deviation of each position of the clastic body detected by an optical sensor or on a basis of a magnitude of a force applied to the elastic body detected by a force sensor.

9. The information processing device according to claim **1**, wherein

the grip portion is provided with a plurality of finger portions, and

the circuitry is further configured to detect the initial slip at each of the finger portions on a basis of a detection result of the pressure distribution sensor.

10. The information processing device according to claim **9**, wherein

the circuitry is further configured to

calculate an inclination of the finger portion gripping the object on a basis of a direction of the initial slip and a force detected by the pressure distribution sensor of each of the finger portions, and

control an operation of the arm portion on a basis of the calculated inclination.

11. The information processing device according to claim **10**, wherein

the circuitry is further configured to calculate the inclination of the finger portion on a basis of posture information indicating an amount of movement of a movable part of each of the finger portions.

12. An information processing method performed by an information processing device, the method comprising:

detecting a slip generated in an object gripped by a finger portion constituting a grip portion that is provided on an arm portion;

estimating an external force and an external moment applied to the object on a basis of the slip generated in the object; and

controlling an operation of the arm portion on a basis of the external force and the external moment to adjust at least one of a position and a posture of the finger portion constituting the grip portion, wherein

the finger portion includes an elastic body that comes into contact with the object when the object is gripped, and a pressure distribution sensor that detects a distribution of pressure applied to the elastic body, and

the method further comprises

detecting an initial slip in which a fixed portion and a slip portion are mixed between the object and the elastic body on a basis of a detection result of the pressure distribution sensor, and

estimating directions and amounts of the external force and the external moment applied to the object on a basis of a direction and an amount of the initial slip.

13. A non-transitory computer-readable medium storing program causing a computer to execute processing comprising:

detecting a slip generated in an object gripped by a finger portion constituting a grip portion that is provided on an arm portion;

estimating an external force and an external moment applied to the object on a basis of the slip generated in the object; and

controlling an operation of the arm portion on a basis of the external force and the external moment to adjust at least one of a position and a posture of the finger portion constituting the grip, wherein

the finger portion includes an elastic body that comes into contact with the object when the object is gripped, and a pressure distribution sensor that detects a distribution of pressure applied to the elastic body, and

the processing further comprises

detecting an initial slip in which a fixed portion and a slip portion are mixed between the object and the elastic body on a basis of a detection result of the pressure distribution sensor, and

estimating directions and amounts of the external force and the external moment applied to the object on a basis of a direction and an amount of the initial slip.

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