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Rebar tying robot

Abstract

A rebar tying robot may include a rebar tying unit, a conveying unit configured to convey the rebar tying unit, and a control unit configured to control an operation of the conveying unit. The conveying unit may include a longitudinal movement mechanism configured to move the rebar tying robot in a front-rear direction, and a first three-dimensional distance sensor configured to output first point cloud data which represents a three-dimensional position of a subject in a first field of view by point clouds. The control unit may be configured to execute a first rebar extraction process in which the control unit extracts point clouds from the point clouds included in the first point cloud data and a rebar model generation process in which the control unit generates a rebar model based on the point clouds extracted in the first rebar extraction process.

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Background/Summary

TECHNICAL FIELD

(1) The art disclosed herein relates to a rebar tying robot.

BACKGROUND ART

(2) Japanese Patent Application Publication No. 2019-39174 describes a rebar tying robot that alternately and repeatedly performs an operation of moving, in a direction in which a plurality of primary rebars extends, over the plurality of primary rebars and a plurality of secondary rebars intersecting the plurality of primary rebars and an operation of tying the plurality of primary rebars and the plurality of secondary rebars at points where the plurality of primary rebars and the plurality of secondary rebars intersect. The rebar tying robot includes a rebar tying unit, a conveying unit that conveys the rebar tying unit, and a control unit that controls an operation of the conveying unit. The conveying unit includes a longitudinal movement mechanism that moves the rebar tying robot in a front-rear direction.

SUMMARY OF INVENTION

Technical Problem

(3) In a rebar tying robot, if a rebar model in which a primary rebar or a secondary rebar is modeled by a linear line can be generated, control of movement of a conveying unit and tying of the rebars by a rebar tying unit can more easily be executed. The disclosure herein provides art that enables generation of a rebar model in which a primary rebar or a secondary rebar is modeled by a linear line in a rebar tying robot.

Solution to Technical Problem

(4) A rebar tying robot disclosed herein may be configured to alternately and repeatedly perform an operation of moving, in a direction in which a plurality of primary rebars extends, over the plurality of primary rebars and a plurality of secondary rebars intersecting the plurality of primary rebars and an operation of tying the plurality of primary rebars and the plurality of secondary rebars at points where the plurality of primary rebars and the plurality of secondary rebars intersect. The rebar tying robot may comprise a rebar tying unit, a conveying unit configured to convey the rebar tying unit, and a control unit configured to control an operation of the conveying unit. The conveying unit may comprise a longitudinal movement mechanism configured to move the rebar tying robot in a front-rear direction and a first three-dimensional distance sensor configured to output first point cloud data which represents a three-dimensional position of a subject in a first field of view by point clouds. The control unit may be configured to execute a first rebar extraction process in which the control unit extracts, from the point clouds included in the first point cloud data, point clouds whose positions in an up-down direction are within a predetermined rebar depth range and a rebar model generation process in which the control unit generates a rebar model in which the primary rebar or the secondary rebar is modeled by a linear line based on the point clouds extracted in the first rebar extraction process.

(5) According to the above configuration, the rebar model of the primary rebar or the secondary rebar can be generated by using the first point cloud data obtained by the first three-dimensional distance sensor. The point clouds included in the first point cloud data obtained by the first three-dimensional distance sensor include not only the point clouds corresponding to the primary rebars and the secondary rebars but also point clouds corresponding to objects located lower than the primary rebars and the secondary rebars, such the ground surface. According to the above configuration, the point clouds corresponding to the primary rebars and the secondary bars can be extracted in the first rebar extraction process, thus accurate rebar model for the primary rebar or the secondary rebar can be generated.

Description

BRIEF DESCRIPTION OF DRAWINGS

(1) FIG. **1** is a perspective view of a rebar tying robot **100** of an embodiment viewed from the front left upper side.

(2) FIG. **2** is a perspective view of a rebar tying machine **2** used in the rebar tying robot **100** of the embodiment viewed om the rear left upper side.

(3) FIG. **3** is a perspective view of an internal structure of a body **4** of the rebar tying machine **2** used in the rebar tying robot **100** of the embodiment viewed from the rear right upper side.

(4) FIG. **4** is a cross-sectional view of a front pan of the body **4** of the rebar tying machine **2** used in the rebar tying robot **100** of the embodiment.

(5) FIG. **5** is a perspective view of internal structures of the body **4** and an upper portion of a grip **6** of the rebar tying machine **2** used in the rebar tying robot **100** of the embodiment viewed from the front left upper side.

(6) FIG. **6** is a perspective view of a power supply unit **102** of the rebar tying robot **100** of the embodiment viewed from the front right upper side in the state where a cover **112** is open.

(7) FIG. **7** is a perspective view of the rebar tying robot **100** of the embodiment in the state where the rebar tying machine **2** is attached to an operation unit **104** viewed from the rear right upper side.

(8) FIG. **8** is a perspective view of the rebar tying robot **100** of the embodiment in the state where the rebar tying machine **2** is attached to a grip mechanism **132** viewed from the rear right lower side.

(9) FIG. **9** is a side view of the operation unit **104** and the rebar tying machine **2** in the state where the rebar tying machine **2** is lifted in the rebar tying robot **100** of the embodiment.

(10) FIG. **10** is a side view of the operation unit **104** and the rebar tying machine **2** in the state where the rebar tying machine **2** is lowered in the rebar tying robot **100** of the embodiment.

(11) FIG. **11** is a perspective view of the rebar tying robot **100** of the embodiment viewed from the front right lower side.

(12) FIG. **12** is a perspective cross-sectional view of a tensioner pulley **224** of the rebar tying robot **100** of the embodiment and its vicinity viewed from the front left upper side.

(13) FIG. **13** is a perspective view of a side stepper **196** of the rebar tying robot **100** of the embodiment viewed from the rear right lower side.

(14) FIG. **14** is a perspective view of a front portion of the side stepper **196** of the rebar tying robot **100** of the embodiment viewed from the rear right upper side.

(15) FIG. **15** is a cross-sectional view of a front crank mechanism **276** of the rebar tying robot **100** of the embodiment viewed from the rear side.

(16) FIG. **16** is a perspective view of a rear portion of the side stepper **196** of the rebar tying robot **100** of the embodiment viewed from the front right upper side.

(17) FIG. **17** is a front view of the rebar tying robot **100** of the embodiment in the state where step bars **272**, **274** are lifted.

(18) FIG. **18** is a front view of the rebar tying robot **100** of the embodiment in the state where the step bars **272**, **274** are lowered.

(19) FIG. **19** is a flowchart showing processes which a control unit **126** executes in the rebar tying robot **100** of the embodiment.

(20) FIG. **20** is a flowchart showing processes which the control unit **126** executes in the rebar tying robot **100** of the embodiment.

(21) FIG. **21** is a top view showing an example of an operation of the rebar tying robot **100** of the embodiment.

(22) FIG. **22** is a top view showing another example of the operation of the rebar tying robot **100** of the embodiment.

(23) FIG. **23** is a top view showing yet another example of the operation of the rebar tying robot **100** of the embodiment.
(24) FIG. **24** is a top view showing an example of a relative positional relationship of the rebar tying robot **100** of the embodiment and a primary rebar R**1**′.
(25) FIG. **25** is a graph showing an example of a trajectory of the rebar tying robot **100** of the embodiment in rebar tracing control.
(26) FIG. **26** is a graph showing an example of a difference in trajectories in the rebar tying robot **100** of the embodiment that occurs due to presence and absence of the rebar tracing control.
(27) FIG. **27** is a graph showing an example of differences in trajectories of the rebar tying robot **100** of the embodiment in various types of rebar tracing control.
(28) FIG. **28** is a flowchart of a side step process which the control unit **126** executes in the rebar tying robot **100** of the embodiment.
(29) FIG. **29** schematically shows point clouds PG**1** which the control unit **126** processes in the side step process in the rebar tying robot **100** of the embodiment.
(30) FIG. **30** schematically shows confirmation areas DR and point clouds PG**2** which the control unit **126** processes in the side step process in the rebar tying robot **100** of the embodiment.
(31) FIG. **31** is a flowchart of a primary rebar model generation process which the control unit **126** executes in the rebar tying robot **100** of the embodiment.
(32) FIG. **32** is a flowchart of the primary rebar model generation process which the control unit **126** executes in the rebar tying robot **100** of the embodiment.
(33) FIG. **33** schematically shows point clouds PG**1** which the control unit **126** processes in the primary rebar model generation process in the rebar tying robot **100** of the embodiment.
(34) FIG. **34** schematically shows point clouds PG**2** and a secondary rebar model RM**2** which the control unit **126** processes in the primary rebar model generation process in the rebar tying robot **100** of the embodiment.
(35) FIG. **35** schematically shows the point clouds PG**1** and the secondary rebar model RM**2** which the control unit **126** processes in the primary rebar model generation process in the rebar tying robot **100** of the embodiment.
(36) FIG. **36** schematically shows point clouds PG**3** and a tentative primary rebar model TRM**1** which the control unit **126** processes in the primary rebar model generation process in the rebar tying robot **100** of the embodiment.
(37) FIG. **37** is a flowchart of an intersecting position identification process which the control unit **126** executes in the rebar tying robot **100** of the embodiment.
(38) FIG. **38** schematically shows point clouds PG**1** and a primary rebar model RM**1** which the control unit **126** processes in the intersecting position identification process in the rebar tying robot **100** of the embodiment.
(39) FIG. **39** schematically shows point clouds PG**2** and the primary rebar model RM**1** which the control unit **126** processes in the intersecting position identification process in the rebar tying robot **100** of the embodiment.
(40) FIG. **40** schematically shows how the control unit **126** generates a rebar model according to a RANSAC method in the rebar tying robot **100** of the embodiment.
(41) FIG. **41** schematically shows how the control unit **126** generates the rebar model according to the RANSAC method in the rebar tying robot **100** of the embodiment.
(42) FIG. **42** schematically shows how the control unit **126** generates the rebar model according to the RANSAC method in the rebar tying robot **100** of the embodiment.

DESCRIPTION OF EMBODIMENTS

(43) Representative, non-limiting examples of the present disclosure will now be described in further detail with reference to the attached drawings. This detailed description is merely intended to teach a person of skill in the art further details for practicing aspects of the present teachings and is not intended to limit the scope of the present disclosure. Furthermore, each of the additional

features and teachings disclosed below may be utilized separately or in conjunction with other features and teachings to provide improved rebar tying robots as well as methods for using and manufacturing the same.
(44) Moreover, combinations of features and steps disclosed in the following detailed description may not be necessary to practice the present disclosure in the broadest sense, and are instead taught merely to particularly describe representative examples of the present disclosure. Furthermore, various features of the above-described and below-described representative examples, as well as the various independent and dependent claims, may be combined in ways that are not specifically and explicitly enumerated in order to provide additional useful embodiments of the present teachings.
(45) All features disclosed in the description and/or the claims are intended to be disclosed separately and independently from each other for the purpose of original written disclosure, as well as for the purpose of restricting the claimed subject matter, independent of the compositions of the features in the embodiments and/or the claims. In addition, all value ranges or indications of groups of entities are intended to disclose every possible intermediate value or intermediate entity for the purpose of original written disclosure, as well as for the purpose of restricting the claimed subject matter.
(46) In one or more embodiments, a rebar tying robot may be configured to alternately and repeatedly perform an operation of moving, in a direction in which a plurality of primary rebars extends over the plurality of primary rebars and a plurality of secondary rebars intersecting the plurality of primary rebars and an operation of tying the plurality of primary rebars and the plurality of secondary rebars at points where the plurality of primary rebars and the plurality of secondary rebars intersect. The rebar tying robot may comprise a rebar tying unit, a conveying unit configured to convey the rebar tying unit, and a control unit configured to control an operation of the conveying unit. The conveying unit may comprise a longitudinal movement mechanism configured to move the rebar tying robot in a front-rear direction and a first three-dimensional distance sensor configured to output first point cloud data which represents a three-dimensional position of an object in a first field of view by point clouds. The control unit may be configured to execute a first rebar extraction process in which the control unit extracts, from the point clouds included in the first point cloud data, point clouds whose positions in an up-down direction are within a predetermined rebar depth range and a rebar model generation process in which the control unit generates a rebar model in which the primary rebar or the secondary rebar is modeled by a linear line based on the point clouds extracted in the first rebar extraction process.
(47) In one or more embodiments, the control unit may be configured to execute a cluster extraction process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds included in a largest cluster. The rebar model generation process may be based on the point clouds extracted in the cluster extraction process.
(48) The point clouds included in the first point cloud data obtained by the first three-dimensional distance sensor may include point clouds corresponding to an object other than the primary rebars and the secondary rebars among the point clouds whose positions in the up-down direction are substantially the same as those of the primary rebars and the secondary rebars. In the point clouds included in the first point cloud data obtained by the first three-dimensional distance sensor, the point clouds corresponding to the primary rebars and the secondary rebars constitute clusters, thus by extracting only the point clouds included in the largest cluster, the point clouds corresponding to objects other than the primary rebars and the secondary rebars can be excluded. According to the above configuration, the point clouds corresponding to the primary rebars and the secondary rebars can more accurately be extracted.
(49) In one or more embodiments, the rebar model generation process may include a secondary rebar model generation process in which the control unit generates a secondary rebar model in which the secondary rebar is modeled based on the point clouds extracted in the first rebar

extraction process, a secondary rebar exclusion process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds that are not included in an area at or in a vicinity of the secondary rebar model, and a primary rebar model generation process in which the control unit generates a primary rebar model in which the primary rebar is modeled based on the point clouds extracted in the secondary rebar exclusion process.
(50) According to the above configuration, the primary rear model is generated based on the point clouds from which the point clouds corresponding to the secondary rebars are excluded and only the point clouds corresponding to the primary rebar are included, thus a more accurate primary rebar model can be generated. The area at or in the vicinity of the secondary rebar model hereof refers for example to an area within which a distance from a linear line represented by the secondary rebar model is within a predetermined value (such as within 1.5 or 1 times a diameter of the secondary rebar).
(51) In one or more embodiments, the rebar model generation process may further include a secondary rebar extraction process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds that are within a secondary rebar candidate area, the secondary rebar candidate area being defined based on positions of point clouds located at or in a vicinity of opposite ends in the left-right direction. The secondary rebar model generation process may be based on the point clouds extracted in the secondary rebar extraction process.
(52) According to the above configuration, since the secondary rebar model is generated in the secondary rebar model generation process based on the point clouds from which many of the point clouds corresponding to the primary rebar are excluded, a more accurate secondary rebar model can be generated. Due to this, the point clouds corresponding to the secondary rebar can more accurately be excluded in the secondary rebar exclusion process that takes place later.
(53) In one or more embodiments, in the secondary rebar model generation process, the secondary rebar model may be generated according to a RANSAC method.
(54) The point clouds used in generating the secondary rebar model in the secondary rebar model generation process include not only the point clouds corresponding to the secondary rebar but also a few point clouds corresponding to the primary rebar. According to the above configuration, the point clouds corresponding to the primary rebar can be handled as outliers by the RANSAC method, thus a more accurate secondary rebar model can be generated in the secondary rebar model generation process.
(55) In one or more embodiments, the first three-dimensional distance sensor may be directed downward.
(56) According to the above configuration, a process for converting a three-dimensional position of an object with the first three-dimensional distance sensor as the reference to a three-dimensional position with the rebar tying robot as the reference can be simplified.
(57) In one or more embodiments, the conveying unit may further comprise a second three-dimensional distance sensor configured to output second point cloud data which represents a three-dimensional position of an object in a second field of view by point clouds, the second field of view being rearward of the first field of view. The control unit may be configured to further execute a second rebar extraction process in which the control unit extracts, from the point clouds included in the second point cloud data, point clouds whose positions in an up-down direction are within the rebar depth range. The rebar model generation process may also be based on the point clouds extracted in the second rebar extraction process.
(58) According to the above configuration, since the rebar model for the primary rebar or the secondary rebar is generated by using the first point cloud data obtained by the first three-dimensional distance sensor and the second point cloud data obtained by the second three-dimensional distance sensor, a more accurate rebar model can be generated.
(59) In one or more embodiments, the rebar model generation process may include a first

secondary rebar model generation process in which the control unit generates a secondary rebar model in which the secondary rebar is modeled based on the point clouds extracted in the first rebar extraction process, a first secondary rebar exclusion process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds that are not included in an area at or in a vicinity of the secondary rebar model generated in the first secondary rebar model generation process, a second secondary rebar model generation process in which the control unit generates a secondary rebar model in which the secondary rebar is modeled based on the point clouds extracted in the second rebar extraction process, a second secondary rebar exclusion process in which the control unit further extracts, from the point clouds extracted in the second rebar extraction process, point clouds that are not included in the area at or in the vicinity of the secondary rebar model generated in the second secondary rebar model generation process, and a primary rebar model generation process in which the control unit generates a primary rebar model in which the primary rebar is modeled based on the point clouds extracted in the first secondary rebar exclusion process and the point clouds extracted in the second secondary rebar exclusion process.

(60) According to the above configuration, the primary rebar model is generated based on: point clouds which are derived from the first point cloud data, include only the point clouds corresponding to the primary rebar and exclude point clouds corresponding to the secondary rebar; and point clouds which are derived from the second point cloud data, include only the point clouds corresponding to the primary rebar and exclude point clouds corresponding to the secondary rebar, thus a more accurate primary rebar model can be generated.

(61) In one or more embodiments, in the primary rebar model generation process, the primary rebar model may be generated according to a least square method.

(62) If the configuration in which the primary rebar model is generated according to the RANSAC method using the point clouds derived from the first point cloud data and the point clouds derived from the second point cloud data is employed, when the number of either the point clouds derived from the first point cloud data or the point clouds derived from the second point cloud data is large and the number of the other thereof is small, all of the point clouds whose number is smaller could be handled as outliers, and an accurate primary rebar model may not be generated. According to the above configuration, since the primary rebar model is generated from the point clouds derived from the first point cloud data and the point clouds derived from the second point cloud data by using the least square method, an accurate primary rebar model can be generated even when the number of either the point clouds derived from the first point cloud data or the point clouds derived from the second point cloud data is large and the number of the other thereof is small.

(63) In one or more embodiments, the first three-dimensional distance sensor and the second three-dimensional distance sensor may be directed downward.

(64) According to the above configuration, a process of converting a three-dimensional position of an object with the first three-dimensional distance sensor or the second three-dimensional distance sensor as the reference into a three-dimensional position with the rebar tying robot as the reference can be simplified.

(65) In one or more embodiments, the conveying unit may comprise a crawler configured to move on the plurality of primary rebars and the plurality of secondary rebars.

(66) When the rebar tying robot moves using the crawler, a moving direction of the rebar tying robot could be deviated in the left-right direction due to various factors even when the rebar tying robot is moved along the primary rebars. According to the above configuration, since the rebar models of the primary rebars and the secondary rebars can be generated using the first point cloud data obtained by the first three-dimensional distance sensor, whether the rebar tying robot is moving along the primary rebar can thus be identified.

Embodiment

(67) As shown in FIG. **1**, a rebar tying robot **100** of the present embodiment comprises a rebar

tying machine **2**, a power supply unit **102**, an operation unit **104**, and a conveying unit **106**. The rebar tying robot **100** is a robot configured to move over a plurality of primary rebars R**1** arranged parallel to each other along a horizontal direction and a plurality of secondary rebars R**2** arranged parallel to each other along the horizontal direction and tie the primary rebars R**1** and the secondary rebars R**2** at points where the primary rebars R**1** and the secondary rebars R**2** intersect by using the rebar tying machine **2**. When the primary rebars R**1** and the secondary rebars R**2** are viewed from above, a direction along which the secondary rebars R**2** extend intersects perpendicularly to a direction along which the primary rebars R**1** extend. Further, the secondary rebars R**2** are arranged on top of the primary rebars R**1**. The primary rebars R**1** are arranged at an interval of 100 mm to 300 mm and the secondary rebars R**2** are arranged at an interval of 100 mm to 300 mm, for example. The rebar tying robot **100** has a dimension of about 900 mm in a front-rear direction and a dimension of about 600 mm in a left-right direction, for example.
(68) (Configuration of Rebar Tying Machine **2**)
(69) Hereinbelow, a configuration of the rebar tying machine **2** will be described with reference to FIGS. **2** to **5**. It is hereby noted that a front-rear direction, a left-right direction, and an up-down direction in the explanation of FIGS. **2** to **5** are not a front-rear direction, a left-right direction, and an up-down direction with the rebar tying robot **100** as the reference, but are a front-rear direction, a left-right direction, and an up-down direction with the rebar tying machine **2** as the reference.
(70) As shown in FIG. **2**, the rebar tying machine **2** is a power tool for tying rebars R intersecting each other (such as a primary rebar R**1** and a second rebar R**2**) by a wire W. The rebar tying machine **2** can be detached from the rebar tying robot **100** and used by a user as a handheld tool and can also be used by attaching it to the rebar tying robot **100**. The rebar tying machine **2** comprises a housing **3**. The housing **3** includes a body **4**, a grip **6** arranged below the body **4**, and a battery receptacle **8** arranged below the grip **6**. A battery pack B may be attached to a lower portion of the battery receptacle **8** as shown in FIG. **2**, or a battery adapter **108** may be attached thereto as shown in FIG. **1**. The battery pack B includes secondary battery cells (not shown) such as lithium-ion battery cells, and is configured to be charged by a charger (not shown). The body **4**, the grip **6**, and the battery receptacle **8** are integrally configured.
(71) As shown in FIG. **3**, a reel **10** on which the wire W is wound is detachably housed in a rear upper portion of the body **4**. As shown in FIG. **2**, the housing **3** includes a reel cover **5** having a shape that covers an upper portion of the reel **10**. The reel cover **5** is rotatably retained by cover retainers **7** arranged at rear left and right sides of the body **4**. The reel cover **5** is configured to open and close by rotating with respect to the body **4**
(72) As shown in FIGS. **3** to **5**, the rebar tying machine **2** comprises a feeder mechanism **12**, a guide mechanism **14**, a brake mechanism **16**, a cutter mechanism **18**, a twister mechanism **20**, and a controller **80**.
(73) As shown in FIG. **3**, the feeder mechanism **12** is configured to feed out the wire W supplied from the reel **10** to the guide mechanism **14** located in a front part of the body **4**. The feeder mechanism **12** includes a feed motor **22**, a driving roller **24**, and a driven roller **26**. The wire W is to be held between the driving roller **24** and the driven roller **26**. The feed motor **22** may for example be a DC brush motor. An operation of the feed motor **22** is controlled by the controller **80**. The feed motor **22** is configured to rotate the driving roller **24**. When the feed motor **22** rotates the driving roller **24**, the driven roller **26** rotates in a reverse direction and the wire W held by the driving roller **24** and the driven roller **26** is thereby fed out toward the guide mechanism **14**, and the wire W is drawn out from the reel **10**.
(74) As shown in FIG. **4**, the guide mechanism **14** is configured to guide the wire W fed out from the feeder mechanism **12** around the rebars R in a loop shape. The guide mechanism **14** includes a guide pipe **28**, an upper curl guide **30**, and a lower curl guide **32**. The rear end of the guide pipe **28** opens into a space between the driving roller **24** and the driven roller **26**. The wire W fed out from the feeder mechanism **12** is fed into the guide pipe **28**. The front end of the guide pipe **28** opens

into the upper curl guide **30**. The upper curl guide **30** includes therein a first guiding passage **34** for guiding the wire W fed from the guide pipe **28** and a second guiding passage (not shown) for guiding the wire W fed from the lower curl guide **32**.
(75) As shown in FIG. **4**, the first guiding passage **34** includes a plurality of guide pins **38** configured to guide the wire W such that they give a downward curl to the wire W and a cutter **40** that constitutes apart of the cutter mechanism **18** to be described later. The wire W fed rom the guide pipe **28** is guided by the guide pins **38** in the first guiding passage **34**, passes through the cutter **40**, and is fed out toward the lower curl guide **32** from the front end of the upper curl guide **30**.
(76) As shown in FIG. **5**, the lower curl guide **32** includes a feed-returning plate **42**. The feed-returning plate **42** is configured to guide the wire W fed out from the front end of the upper curl guide **30** to return the wire W to the rear end of the second guiding passage of the upper curl guide **30**.
(77) The second guiding passage of the upper curl guide **30** is arranged adjacent to the first guiding passage **34**. The second guiding passage is configured to guide the wire W fed from the lower curl guide **32** and feed it out from the front end of the upper curl guide **30** toward the lower curl guide **32**.
(78) The wire W fed out from the feeder mechanism **12** is wound in the loop shape wound the rebars R by the upper curl guide **30** and the lower curl guide **32**. The number of turns of the wire W around the rebars R can be preset by the user. When the feeder mechanism **12** feeds out the wire W by a feed amount corresponding to the set number of turns, it stops the feed motor **22** and thus stops feeding out the wire W.
(79) The brake mechanism **16** shown in FIG. **3** is configured to stop rotation of the reel **10** in conjunction with the feeder mechanism **12** stopping feeding out the wire W. The brake mechanism **16** includes a solenoid **46**, a link **48**, and a brake arm **50**. An operation of the solenoid **46** is controlled by the controller **80**. The reel **10** includes engagement portions **10***a* arranged along its radial direction at a predetermined angular interval and each engagement portion **10***a* is configured to engage with the brake arm **50**. With the solenoid **46** not electrically actuated, the brake arm **50** is separated from the engagement portions **10***a* of the reel **10**. With the solenoid **46** electrically actuated, the brake arm **50** is driven via the link **48**, and the brake arm **50** engages with the engagement portions **10***a* of the reel **10**. When the feeder mechanism **12** is to feed out the wire W, the controller **80** maintains the brake arm **50** separated from the engagement portions **10***a* of the reel **10** by not electrically actuating the solenoid **46**. Due to this, the reel **10** can rotate freely, and the feeder mechanism **12** can draw out the wire W from the reel **10**. Further, when the feeder mechanism **12** stops feeding out the wire W, the controller **80** electrically actuates the solenoid **46** and causes the brake arm **50** to engage with the engagement portions **10***a* of the reel **10**. As a result, rotation of the reel **10** is prohibited. Due to this, the wire W can be prevented from sagging between the reel **10** and the feeder mechanism **12**, which would be caused by the reel **10** continuing to rotate by inertia even after the feeder mechanism **12** has stopped feeding out the wire W.
(80) The cutter mechanism IS shown in FIGS. **4** and **5** is configured to cut the wire W with the wire W wrapped around the rebars R. The cutter mechanism **18** includes the cutter **40** and a link **52**. The link **52** is configured to cooperate with the twister mechanism **20** to be described later and rotates the cutter **40**. The wire W passing through the cutter **40** is cut by rotation of the cutter **40**.
(81) The twister mechanism **20** shown in FIG. **5** is configured to tie the rebars R with the wire W by twisting the wire W wrapped around the rebars R. The twister mechanism **20** includes a twisting motor **54**, a reduction gear mechanism **56**, a screw shaft **58** (see FIG. **4**), a sleeve **60**, a push plate **61**, and a pair of hooks **62**.
(82) The twisting motor **54** may for example be a DC brushless motor. An operation of the twisting motor **54** is controlled by the controller **80**. Rotation of the twisting motor **54** is transmitted to the screw shaft **58** through the reduction gear mechanism **56**. The twisting motor **54** is configured to

rotate in a forward direction and in a reverse direction, in response to which the screw shaft **58** is also configured to rotate in a forward direction and a reverse direction. The sleeve **60** is arranged to surround a periphery of the screw shaft **58**. In the state in which rotation of the sleeve **60** is prohibited, the sleeve **60** moves forward when the screw shaft **58** rotates in the forward direction, and the sleeve **60** moves rearward when the screw shaft **58** rotates in the reverse direction. The push plate **61** is configured to move integrally with the sleeve **60** in the front-rear direction in response to movement of the sleeve **60** in the front-rear direction. Further, when the screw shaft **58** rotates in the state in which the rotation of the sleeve **60** is permitted, the sleeve **60** rotates together with the screw shaft **58**.

(83) When the sleeve **60** advances to a predetermined position from its initial position, the push plate **61** drives the link **52** of the cutter mechanism **18** and rotates the cutter **40**. The pair of hooks **62** is arranged at the front end of the sleeve **60**, and is configured to open and close according to the position of the sleeve **60** in the front-rear direction. When the sleeve **60** moves forward, the pair of hooks **62** closes and grasps the wire W. After this, when the sleeve **60** moves rearward, the pair of hooks **62** opens and releases the wire W.

(84) The controller **80** rotates the twisting motor **54** with the wire W wrapped around the rebars R. At this occasion, the rotation of the sleeve **60** is prohibited, and the sleeve **60** moves forward by the rotation of the screw shaft **58** and also the push plate **61** and the pair of hooks **62** thereby move forward, by which the pair of hooks **62** closes and grasps the wire W. Then, when the rotation of the sleeve **60** is permitted, the sleeve **60** rotates by the rotation of the screw shaft **58**, and along with this the pair of hooks **62** rotates. Due to this, the wire W is twisted and the rebars R are thereby tied.

(85) When twisting of the wire W is completed, the controller **80** rotates the twisting motor **54** in a reverse direction. At this occasion, the rotation of the sleeve **60** is prohibited, and after the pair of books **62** opens and the wire W is thereby released, the sleeve **60** moves rearward by the rotation of the screw shaft **58**, and along with this the push plate **61** and the pair of hooks **62** also move rearward. Due to the sleeve **60** moving rearward, the push plate **61** drives the link **52** of the cutter mechanism **18**, which returns the cutter **40** to its initial posture. After this, when the sleeve **60** moves back to the initial position, the rotation of the sleeve **60** is permitted, by which the sleeve **60** and the pair of hooks **62** rotate by the rotation of the screw shaft **58** and return to the initial angle.

(86) As shown in FIG. **2**, a first operation section **64** is arranged at an upper portion of the body **4**. The first operation section **64** includes a main switch **74** configured to switch on/off of main power, a main power LED **76** that indicates an on/off state of the main power, and the like. The first operation section **64** is connected to the controller **80**.

(87) A second operation section **90** is arranged on a front upper surface of the battery receptacle **8**. The user can set the number of turns of the wire W to be wrapped around the rebars R, a torque threshold for twisting the wire W, and the like through the second operation section **90**. The second operation section **90** includes setting switches **98** for setting the number of turns of the wire W to be wrapped around the rebars R and the torque threshold for twisting the wire W, display LEDs **96** for displaying current settings, and the like. The second operation section **90** is connected to the controller **80**.

(88) As shown in FIGS. **2** to **5**, with the rebar tying machine **2** detached from the rebar tying robot **100**, the user uses the rebar tying machine **2** while holding the grip **6**. A trigger **84** which can be pulled by the user is arranged at a front upper portion of the grip **6**. As shown in FIG. **5**, a trigger switch **86** configured to detect on/off of the trigger **84** is arranged inside the grip **6**. The trigger switch **86** is connected to the controller **80**. When the user pulls the trigger **84** and the trigger switch **86** thereby turns on, the rebar tying machine **2** performs a series of operations of wrapping the wire W around the rebars R by the feeder mechanism **12**, the guide mechanism **14**, and the brake mechanism **16**, cutting the wire W and twisting the wire W wrapped on the rebars R by the cutter mechanism **18** and the twister mechanism **20**.

(89) (Configuration of Power Supply Unit **102**)
(90) As shown in FIG. **1**, the power supply unit **102** is supported by the conveying unit **106**. The power supply unit **102** includes a housing **110** and a cover **112**. A control unit **126** is housed in the housing **110**. The control unit **126** is configured to control operations of the power supply unit **102**, the operation unit **104**, and the conveying unit **106**.
(91) As shown in FIG. **6**, a battery housing chamber **110***a* is defined in the housing **110**. The battery housing chamber **110***a* includes a plurality of battery receptacles **114**. One of a plurality of battery packs B can be detachably attached to each of the plurality of battery receptacles **114**. The cover **112** is attached to the housing **110** via hinges **115** arranged at rear portions of the housing **110** at the vicinity of the upper end of the battery housing chamber **110***a*. The cover **112** is configured to pivot about a pivot axis extending in the left-right direction relative to the housing **110**. As shown in FIG. **6**, with the cover **112** opened relative to the housing **110**, the plurality of battery packs B can be detachably attached to the plurality of battery receptacles **114** by sliding in the up-down direction. As shown in FIG. **1**, when the cover **112** is closed relative to the housing **110**, peripheries of the plurality of battery packs B attached to the plurality of battery receptacles **114** are surrounded by the housing **110** and the cover **112**. In this state, the plurality of battery packs B inside the battery housing chamber **110***a* can be prevented from getting wet even when the power supply unit **102** gets wet with water.
(92) The cover **112** is biased by a torsion spring that is not shown in a closing direction relative to the housing **110**. A latch member **116** which the user can operate is arranged on the cover **112**. As shown in FIG. **6**, a latch receiver **110***b* corresponding to the latch member **116** is arranged on the housing **110**. When the user closes the cover **112** and pivots the latch member **116**, the latch member **116** engages with the latch receiver **110***b*, by which the cover **112** is maintained in the closed state relative to the housing **110**. From this state, when the user pivots the latch member **116** in a reverse direction, engagement between the latch member **116** and the latch receiver **110***b* is released, and the user can thereby open the cover **112** relative to the housing **110**.
(93) A plurality of remaining charge indicators **118**, a remaining charge display button **120**, and an operation execution button **122** are arranged on an upper surface of the housing **110** frontward of the battery housing chamber **110***a*. Each of the plurality of remaining charge indicators **118** is arranged corresponding to one of the plurality of battery receptacles **114**, and is configured to display remaining charge in the battery pack B attached to its corresponding battery receptacle **114**. The remaining charge display button **120** is a button for the user to switch on/off the display of the remaining charge by the plurality of remaining charge indicators **118**. The operation execution button **122** is a button for the user to switch between executing and stopping of the operation of the rebar tying robot **100**.
(94) A power supply cable **124** is connected to the upper surface of the housing **110** frontward of the battery housing chamber **110***a*. The battery adapter **108** is connected to the power supply cable **124**. With the battery adapter **108** attached to the rebar tying machine **2**, power from the plurality of battery packs B is supplied to the rebar tying machine **2**.
(95) A key receptacle **119** to which a key **117** can be detachably attached is arranged in the battery housing chamber **110***a*. The key **117** can be attached or detached by being inserted into or withdrawn from the key receptacle **119**. With the key **117** detached from the key receptacle **119**, power supply from the plurality of battery packs B to the rebar tying machine **2**, the operation unit **104**, and the conveying unit **106** is cut of. With the key **117** attached to the key receptacle **119**, the power supply from the plurality of battery packs B to the rebar tying machine **2**, the operation unit **104**, and the conveying unit **106** is permitted.
(96) (Configuration of Operation Unit **104**)
(97) As shown in FIGS. **7** and **8**, the operation unit **104** includes a lift mechanism **130** and a grip mechanism **132**.
(98) As shown in FIG. **7**, the lift mechanism **130** includes a lower base member **134**, an upper base

member **136**, support pipes **138**, **140**, a lifter **142**, a screw shaft **144**, a motor connector **146**, a lift motor **148**, a sensor supporting member **150**, an upper limit detection sensor **152**, and a lower limit detection sensor **154**. The lower base member **134** is supported by the conveying unit **106**. The lower ends of the support pipes **138**, **140** are fixed to the lower base member **134**. The upper ends of the support pipes **138**, **140** are fixed to the upper base member **136**. The support pipes **138**, **140** are arranged parallel to each other. The support pipes **138**, **140** are arranged such that they are inclined in both the front-rear direction and the left-right direction with respect to the up-down direction of the rebar tying robot **100**. Hereinbelow, a direction along which the support pipes **138**, **140** extend may be termed a lifting direction. Through holes **142***a*, **142***b* through which the support pipes **138**, **140** penetrate are defined in the lifter **142**. Retaining members **156**, **158** configured to slidably retain the support pipes **138**, **140** are fixed to the through holes **142***a*, **142***b*. The retaining members **156**, **158** may tor example be linear bushes in which solid lubricant is embedded, linear ball bearings, or oilless bearings. The lifter **142** is arranged between the lower base member **134** and the upper base member **136** in the state in which each of the support pipes **138**, **140** is slidably penetrating a corresponding one of the retaining members **156**, **158**. The screw shaft **144** is arranged between the support pipes **138**, **140**. The lower end of the screw shat **144** is rotatably supported by the lower base member **134**. The vicinity of the upper end of the screw shaft **144** is rotatably supported by the upper base member **136**. The screw shaft **144** is arranged parallel to the support pipes **138**, **140**. An external thread is defined on an outer surface of the screw shaft **144** at a portion between the lower base member **134** and the upper base member **136**. The lifter **142** includes a through hole **142***c* through which the screw shaft **144** penetrates. A nut **160** is fixed to the through hole **142***c*. An internal thread corresponding to the external thread of the screw shaft **144** is defined on the not **160**. The screw shaft **144** penetrates the lifter **142** with its extremal thread screw-fitted with the internal thread of the nut **160**. The upper end of the screw shaft **144** is coupled to the lift motor **148** via the motor connector **146**. The lift motor **148** may for example be a DC brush motor. When the lift motor **148** rotates in a forward direction, the lifter **142** is lowered in a direction from the upper base member **136** toward the lower base member **134** by rotation of the screw shaft **144**. On the other hand, when the lift motor **148** rotates in a reverse direction, the lifter **142** is lifted in a direction from the lower base member **134** toward the upper base member **136** by rotation of the screw shaft **144**. The sensor supporting member **150** has its lower end fixed to the lower base member **134** and its upper end fixed to the upper base member **136**. Each of the upper limit detection sensor **152** and the lower limit detection sensor **154** is fixed to the sensor supporting member **150**. The upper limit detection sensor **152** is normally off, and turns on by contacting the lifter **142** when the lifter **142** reaches an upper limit position. The lower limit detection sensor **154** is normally off, and turns on by contacting the lifter **142** when the lifter **142** reaches a lower limit position. When the rebar tying machine **2** is to be lowered, the control unit **126** of the rebar tying robot **100** rotates the lift motor **148** in the forward direction, and stops the lift motor **148** when the lower limit detection sensor **154** turns on. The control unit **126** also stops the lift motor **148** in the case in which the rebar tying machine **2** collides with the primary rebars R**1**, the secondary rebars R**2**, or other obstacles when the rebar tying machine **2** is lowered and a load applied to the lift motor **148** thereby increases abruptly. The load applied to the lift motor **148** may be identified for example from a current value of the lift motor **148**. When the rebar tying machine **2** is to be lifted, the control unit **126** rotates the lift motor **148** in the reverse direction and stops the lift motor **148** when the upper limit detection sensor **152** turns on.

(99) As shown in FIGS. **9** and **10**, in the rebar tying robot **100** of the present embodiment, when the rebar tying machine **2** is lowered, the primary rebar R**1** and the second rebar R**2** become closer to the rebar tying machine **2** at positions closer to the lower curl guide **32** than to the upper curl guide **30**. Due to this, in lowering the rebar tying machine **2**, the primary rebar R**1** and the second rebar R**2** can be suppressed from colliding with the upper curl guide **30**. Further, in the rebar tying robot **100** of the present embodiment, when the rebar tying machine **2** is lifted, the primary rebar R**1** and

the second rebar R**2** become distant from the rebar tying machine **2** toward positions closer to the lower curl guide **32** than to the upper curl guide **30**. Due to this, in lifting the rebar tying machine **2**, the primary rebar R**1** and the second rebar R**2** can be suppressed from being caught on the upper curl guide **30**.
(100) As shown in FIG. **8**, the grip mechanism **132** includes a first support plate **162**, a second support plate **164**, coupling shafts **166**, **168**, a pivot pin **170**, a torsion spring **172**, a support pin **174**, a link **176**, a plunger **178**, an actuator **180**, and a torsion spring **182**. The first support plate **162** is arranged facing one outer surface of the grip **6** of the rebar tying machine **2** (such as a right outer surface as viewed from the rebar tying machine **2**). The second support plate **164** is arranged facing the other outer surface of the grip **6** of the rebar tying machine **2** (such as a left outer surface as viewed from the rebar tying machine **2**). The first support plate **162** and the second support plate **164** are fixed to each other via the coupling shafts **166**, **168** while holding the grip **6** of the rebar tying machine **2** between them. A surface of the first support plate **162** facing the grip **6** and a surface of the second support plate **164** facing the grip **6** each have a plurality of protrusions (not shown) defined thereon that is to fit with a plurality of recesses **6***a* (see FIG. **2**) defined on a corresponding outer surface of the grip **6** of the rebar tying machine **2**. Due to this, a position of the grip **6** of the rebar tying machine **2** is fixed relative to the first support plate **162** and the second support plate **164**.
(101) The first support plate **162** is coupled to the lifter **142** of the lift mechanism **130** via the pivot pin **170**. One end of the pivot pin **170** is fixed to the lifter **142**. The other end of the pivot pin **170** is pivotably supported by the first support plate **162**. Due to this, the rebar tying machine **2** supported by the first support plate **162** and the second support plate **164** can be lifted or lowered according to lifting or lowering motion of the lifter **142** and can pivot about the pivot pin **170** relative to the lifter **142**. The support pin **174** is fixed to the lifter **142** and extends from the lifter **142** toward the first support plate **162**. The first support plate **162** includes a long hole **162***a* through which the support pin **174** is to be inserted and a protrusion **162***b* protruding toward the lifter **142**. The long hole **162***a* defines a pivoting range for the rebar tying machine **2** to pivot about the pivot pin **170**. The torsion spring **172** is arranged outside the pivot pin **170** and biases the protrusion **162***b* relative to the support pin **174** in a direction along which the protrusion **162***b* separates away from the support pin **174** (that is, biases the first support plate **162** relative to the lifter **142**). If the rebar tying machine **2** is configured such that it cannot pivot relative to the lifter **142**, a large impact acts on the operation unit **104** when an obstacle collides with the rebar tying machine **2**. By configuring the rebar tying machine **2** as above to be pivotable relative to the lifter **142**, such a large impact can be suppressed from acting on the operation unit **104** when the rebar tying machine **2** collides with an obstacle.
(102) The link **176** is supported by the second support plate **164**. The link **176** is pivotable relative to the second support plate **164** about a pivot axis extending along the left-right direction. The link **176** includes a presser portion **176**, and an operation portion **176***b*. The presser portion **176***a* is arranged facing the trigger **84** of the rebar tying machine **2**. The operation portion **176***b* is coupled to the actuator **180** via the plunger **178**. The actuator **180** may for example be a solenoid. An operation of the actuator **180** is controlled by the control unit **126** of the rebar tying robot **100**. The torsion spring **182** biases the link **176** relative to the second support plate **164** in a direction along which the presser portion **176***a* separates away from the trigger **84**. When the actuator **180** is off, the presser portion **176***a* is separated away from the trigger **84** by a biasing force of the torsion spring **182**. When the actuator **180** turns on, the link **176** pivots in a direction by which the operation portion **176***b* approaches toward the actuator **180**, and the presser portion **176***a* thereby presses the trigger **84**. Due to this, the operation of pulling the trigger **84** of the rebar tying machine **2** is carried out.
(103) (Configuration of Conveying Unit **106**)
(104) As shown in FIG. **11**, the conveying unit **106** includes a carrier **190**, a right crawler **192**, a left

crawler **194**, a side stepper **196**, a front three-dimensional distance sensor **198**, a rear three-dimensional distance sensor **200**, and a central three-dimensional distance sensor **202**.
(105) The carrier **190** includes a base plate **204**, a right frame **206**, a left frame **208**, a right plate **210**, a left plate **212**, a front frame **214**, and a rear frame **216**. The base plate **204** is arranged along the front-rear direction and the left-right direction. As shown in FIG. **1**, the power supply unit **102** is supported by the conveying unit **106** by having the housing **110** fixed to an upper surface of the base plate **204**. A through hole **204***a* is defined in the base plate **204**. As shown in FIG. **11**, the operation unit **104** is supported by the conveying unit **106** by fixing the lower base member **134** to an edge of the through hole **204***a*. When the operation unit **104** is to lift or lower the rebar tying machine **2**, the rebar tying machine **2** moves through the through hole **204***a*.
(106) The right frame **206** and the left frame **208** are fixed to a lower surface of the base plate **204**. The right frame **206** extends in the front-rear direction at the right end of the base plate **204**. The left frame **208** extends in the front-rear direction at the left end of the base plate **204**. In the front-rear direction, the front end of the right frame **206** and the front end of the left frame **208** are located at the same position as the front end of the base plate **204**, and the rear end of the right frame **206** and the rear end of the left frame **208** are located at the same position as the rear end of the base plate **204**. The right plate **210** is fixed to a right surface of the right frame **206**. The right plate **210** is arranged along the front-rear direction and the up-down direction. The left plate **212** is fixed to a left surface of the left frame **208**. The left plate **212** is arranged along the front-rear direction and the up-down direction. In the up-down direction, the upper end of the right plate **210** and the upper end of the left plate **212** are located at the same position as the upper surface of the base plate **204**. In the front-rea direction, the front end of the right plate **210** and the front end of the left plate **212** protrude frontward beyond the front end of the base plate **204**, and the rear end of the right plate **210** and the rear end of the left plate **212** protrude rearward beyond the rear end of the base plate **204**. The front frame **214** couples a portion of the right plate **210** at the vicinity of its front end and a portion of the left plate **212** at the vicinity of its front end at a position on the frontward of the front end of the base plate **204**. The rear frame **216** couples a portion of the right plate **210** at the vicinity of the rear end and a portion of the left plate **212** at the vicinity of the rear end at a position rearward of the rear end of the base plate **204**. The front frame **214** and the rear frame **216** extend in the left-right direction. In the up-down direction, the front frame **214** and the rear frame **216** are positioned lower than the right frame **206** and the left frame **208**.
(107) The right crawler **192** includes a front pulley **218**, a rear pulley **220**, a plurality of auxiliary pulleys **222**, a tensioner pulley **224**, a rubber belt **226**, a right crawler motor **228**, and a gearbox **230**. Teeth configured to mesh with the rubber belt **226** are defined on an outer surface of the front pulley **218**, an outer surface of the rear pulley **220**, and outer surfaces of the plurality of auxiliary pulleys **222**. The rubber belt **226** is strapped over each of the front pulley **218**, the rear pulley **220**, the plurality of auxiliary pulleys **222**, and the tensioner pulley **224**. The front pulley **218** is rotatably supported by the right plate **210** via a bearing **232** in the vicinity of the front end of the right plate **210**. The rear pulley **220** is rotatably supported by the right plate **210** via a bearing **234** at the vicinity of the rear end of the right plate **210**. The plurality of auxiliary pulleys **222** is rotatably supported by the right plate **210** via bearings **236** between the front pulley **218** and the rear pulley **220**. The plurality of auxiliary pulleys **222** is arranged along the front-rear direction. An outer diameter of the front pulley **218** and an outer diameter of the rear pulley **220** are substantially the same, and an outer diameter of each of the plurality of auxiliary pulleys **222** is smaller than the outer diameters of the front pulley **218** and the rear pulley **220**. In the up-down direction, the lower end of the front pulley **218**, the lower end of the rear pulley **220**, and the lower ends of the plurality of auxiliary pulleys **222** are located at the substantially sane position.
(108) As shown in FIG. **12**, the tensioner pulley **224** is rotatably supported by a movable bearing **237**. The movable bearing **237** is supported by the right plate **210** such that the movable bearing **237** can move in the up-down direction. The base plate **204** and the right frame **206** are cut away in

the vicinity of the movable bearing **237** so that they do not interfere with the movable bearing **237**. An adjustment bolt **238**, a nut **240**, and a bolt supporting member **242** are arranged below the movable bearing **237**. The bolt supporting member **242** is fixed to the right plate **210**. A through hole **242***a* through which a shaft **238***a* of the adjustment bolt **238** penetrates is defined in the bolt supporting member **242**. An internal thread corresponding to an external thread on the shaft **238***a* is defined on an inner surface of the through hole **242***a*. The nut **240** is arranged below the bolt supporting member **242**. A head **238***b* of the adjustment bolt **238** is arranged below the nut **240**, and the shaft **238***a* of the adjustment bolt **238** is screw-fitted with the nut **240** and with the through hole **242***a* of the bolt supporting member **242**. Due to this, a position of the adjustment bolt **238** in the up-down direction is fixed by a so-called double nut structure. The upper end of the shaft **238***a* of the adjustment bolt **238** abuts a lower surface of the movable bearing **237**. By adjusting the position of the adjustment bolt **238** in the up-down direction with the rubber belt **226** strapped over the tensioner pulley **224**, a position of the movable bearing **237** relative to the right plate **210** in the up-down direction can be adjusted. Due to this, a degree of tension of the rubber belt **226** can be adjusted.

(109) As shown in FIG. **11**, the right crawler motor **228** is supported by the right plate **210** via the bearing **232** and the gearbox **230**. The right crawler motor **228** may for example be a DC brushless motor. The right crawler motor **228** is coupled to the front pulley **218** via a reduction gear (not shown) incorporated in the gearbox **230**. When the right crawler motor **228** rotates in a forward direction or a reverse direction, the front pulley **218** rotates in a forward direction or a reverse direction, by which the rubber belt **226** rotates in a forward direction or a reverse direction on the outside of the front pulley **218**, the rear pulley **220**, the plurality of auxiliary pulleys **222**, and the tensioner pulley **224**.

(110) The left crawler **194** includes a front pulley **244**, a rear pulley **246**, a plurality of auxiliary pulleys **248**, a tensioner pulley **250**, a rubber belt **252**, a left crawler motor **254**, and a gearbox **256**. Teeth configured to mesh with the rubber belt **252** are defined on an outer surface of the front pulley **244**, an outer surface of the rear pulley **246**, and outer surfaces of the plurality of auxiliary pulleys **248**. The rubber belt **252** is strapped over the front pulley **244**, the rear pulley **246**, the plurality of auxiliary pulleys **248**, and the tensioner pulley **250**. The front pulley **244** is rotatably supported by the left plate **212** via a bearing **258** at the vicinity of the front end of the left plate **212**. The rear pulley **246** is rotatably supported by the left plate **212** via a bearing **260** at the vicinity of the rear end of the left plate **212**. The plurality of auxiliary pulleys **248** is rotatably supported by the left plate **212** via bearings **262** between the front pulley **244** and the rear pulley **246**. The plurality of auxiliary pulleys **248** is arranged along the front-rear direction. An outer diameter of the front pulley **244** and an outer diameter of the rear pulley **246** are substantially the same, and an outer diameter of each of the plurality of auxiliary pulleys **248** is smaller than the outer diameters of the front pulley **244** and the rear pulley **246**. In the up-down direction, the lower end of the front pulley **244**, the lower end of the rear pulley **246**, and the lower ends of the plurality of auxiliary pulleys **248** are at the substantially same position.

(111) As shown in FIG. **12**, the tensioner pulley **250** is rotatably supported by a movable bearing **264**. The movable bearing **264** is supported by the left plate **212** such that the movable bearing **264** can move in the op-down direction. The base plate **204** and the left frame **208** are cut away in the vicinity of the movable bearing **264** so that they do not interfere with the movable bearing **264**. An adjustment bolt **266**, a nut **268**, and a bolt supporting member **270** are arranged below the movable bearing **264**. The bolt supporting member **270** is fixed to the left plate **212**. A through hole **270***a* through which a shaft **266***a* of the adjustment bolt **266** penetrates is defined in the bolt supporting member **270**. An internal thread corresponding to an external thread on the shaft **266***a* is defined on an inner surface of the through hole **270***a*. The nut **268** is arranged below the bolt supporting member **270**. A head **266***b* of the adjustment bolt **266** is arranged below the nut **268**, and the shaft **266***a* of the adjustment bolt **266** is screw-fitted with the nut **268** and with the through hole **270***a* of

the bolt supporting member **270**. Due to this, a position of the adjustment bolt **266** in the up-down direction is fixed by a so-called double nut structure. The upper end of the shaft **266***a* of the adjustment bolt **266** abuts a lower surface of the movable bearing **264**. By adjusting the position of the adjustment bolt **266** in the up-down direction with the rubber belt **252** strapped over the tensioner pulley **250**, a position of the movable bearing **264** relative to the left plate **212** in the up-down direction can be adjusted. Due to this, a degree of tension of the rubber belt **252** can be adjusted.
(112) As shown in FIG. **11**, the left crawler motor **254** is supported by the left plate **212** via the bearing **258** and the gearbox **256**. The left crawler motor **254** may for example be a DC brushless motor. The left crawler motor **254** is coupled to the front pulley **244** via a reduction gear (not shown) incorporated in the gearbox **256**. When the left crawler motor **254** rotates in a forward direction or a reverse direction, the front pulley **244** rotates in a forward direction or a reverse direction, by which the rubber belt **252** rotates in a forward direction or a reverse direction on the outside of the front pulley **244**, the rear pulley **246**, the plurality of auxiliary pulleys **248**, and the tensioner pulley **250**.
(113) As shown in FIG. **13**, the side stepper **196** includes step bars **272**, **274**, a front crank mechanism **276**, a rear crank mechanism **277**, a stepper motor **279**, a gearbox **281**, a worm gear casing **283**, and a rotation transmitting shaft **285**. The step bars **272**, **274** are bar-shaped members with a substantially rectangular cross section, and extend in the front-rear direction. As shown in FIG. **11**, in the left-right direction, the step bar **272** is arranged between the center and the right end of the base plate **204**, and the step bar **274** is arranged between the center and the left end of the base plate **204**.
(114) As shown in FIGS. **13** and **14**, the front crank mechanism **276** includes a support plate **278**, pulleys **280**, **282**, a belt **284**, crank arms **286**, **288**, crank pins **290**, **292** (see FIG. **15**), a crank plate **294**, rollers **296**, **298**, and a guide plate **300**. The support plate **278** is fixed to the lower surface of the base plate **204** at the vicinity of the front end of the base plate **204**. The support plate **278** is arranged along the left-right direction and the up-down direction. The pulley **280** is arranged rearward of the support plate **278** at the vicinity of the right end of the support plate **278**. The pulley **282** is arranged rearward of the support plate **278** in the vicinity of the left end of the support plate **278**. The pulleys **280**, **282** are supported rotatably by the support plate **278**. A diameter of the pulley **280** is substantially the same as a diameter of the pulley **282**. The belt **284** is strapped over each of the pulleys **280**, **282**. Due to this, when one of the pulleys **280**, **282** rotates in a forward direction or a reverse direction, the other thereof rotates in the forward direction or the reverse direction at substantially the same rotational speed.
(115) The crank arms **286**, **288**, the crank pins **290**, **292**, the crank plate **294**, the rollers **296**, **298**, and the guide plate **300** are arranged frontward of the support plate **278**. As shown in FIG. **15**, the crank arms **286**, **288** include fitting holes **286***a*, **288***a* to which shafts **280***a*, **282***a* of the pulleys **280**, **282** are fitted, and long holes **286***b*, **288***b* extending in a longitudinal direction of the crank arms **286**, **288**. When the pulleys **280**, **282** rotate, the crank arms **286**, **288** rotate integrally with the pulleys **280**, **282** about the shafts **280***a*, **282***a*. The crank pins **290**, **292** are slidably inserted into the long holes **286***b*. **288***b*. The crank pins **290**, **292** are fixed to the crank plate **294** with the crank pins **290**, **292** penetrating the crank plate **294**. The crank plate **294** is arranged frontward of the crank arms **286**, **288**. The crank plate **294** extends in the left-right direction and the up-down direction. The rollers **296**, **298** (see FIG. **14**) are attached to the crank pins **290**, **292** frontward of the crank plate **294**. As shown in FIG. **14**, the rollers **296**, **298** are accommodated in guide grooves **302**, **304** defined in a rear surface of the guide plate **300**. The guide plate **300** is fixed to the lower surface of the base plate **204** frontward of the crank plate **294**. The guide plate **300** extends in the left-right direction and the up-down direction. As shown in FIG. **15**, the guide grooves **302**, **304** of the guide plate **300** have substantially rectangular shapes with rounded corners. The guide grooves **302**, **304** define a side-stepping track S shown by a broken line in FIG. **15**. The side-stepping track S has a

substantially rectangular shape with rounded corners, and includes upper and lower edges extending along the left-right direction, and right and left edges extending along the up-down direction.

(116) In the front crank mechanism **276**, when the pulleys **280**, **282** rotate, the crank pins **290**, **292** move in a rotating direction of the crank arms **286**, **288** by rotation of the crank arms **286**, **288**. Here, since the rollers **296**, **298** are accommodated in the guide grooves **302**, **304**, the crank pins **290**, **292** move along the side-stepping track S defined by the guide grooves **302**, **304** while sliding inside the long holes **286***b*, **288***b*. Due to this, the crank plate **294** to which the crank pins **290**, **292** are fixed also moves along the side-stepping track S defined by the guide grooves **302**, **304**.

(117) As shown in FIG. **16**, the rear crank mechanism **277** includes a support plate **306**, pulleys **308**, **310**, a belt **312**, crank arms **314**, **316**, crank pins **318**, **320** (see FIG. **15**), a crank plate **322**, rollers **324**, **326**, and a guide plate **328**. The support plate **306** is fixed to the lower surface of the base plate **204** at the vicinity of the rear end of the base plate **204**. The support plate **306** is arranged along the left-right direction and the up-down direction. The pulley **308** is arranged frontward of the support plate **306** at the vicinity of the right end of the support plate **306**. The pulley **310** is arranged frontward of the support plate **306** at the vicinity of the left end of the support plate **306**. The pulleys **308**, **310** are supported rotatably by the support plate **306**. A diameter of the pulley **308** is substantially the same as a diameter of the pulley **310**, and is substantially the same as the diameter of each of the pulleys **280**, **282** of the front crank mechanism **276**. The belt **312** is strapped over each of the pulleys **308**, **310**. Due to this, when one of the pulleys **308**, **310** rotates in a forward direction or a reverse direction, the other thereof rotates in the forward direction or the reverse direction at substantially the same rotational speed.

(118) The crank arms **314**, **316**, the crank pins **318**, **320**, the crank plate **322**, the rollers **324**, **326**, and the guide plate **328** are arranged rearward of the support plate **306**. As shown in FIG. **15**, the crank arms **314**, **316** include fitting holes **314***a*, **316***a* to which shafts **308***a*, **310***a* of the pulleys **308**, **310** are fitted, and long holes **314***b*. **316***b* extending in a longitudinal direction of the crank arms **314**, **316**. When the pulleys **308**, **310** rotate, the crank arms **314**, **316** rotate integrally with the pulleys **308**, **310** about the shafts **308***a*, **310***a*. The crank pins **318**, **320** are slidably inserted into the long holes **314***b*, **316***b*. The crank pins **318**, **320** are fixed to the crank plate **322** with the crank pins **318**, **320** penetrating the crank plate **322**. The crank plate **322** is arranged rearward of the crank arms **314**, **316**. The crank plate **322** extends in the left-right direction and the up-down direction. The rollers **324**, **326** (see FIG. **16**) are attached to the crank pins **318**, **320** at positions rearward of the crank plate **322**. As shown in FIG. **16**, the rollers **324**, **326** are accommodated in guide grooves **330**, **332** defined in a front surface of the guide plate **328**. The guide plate **328** is fixed to the lower surface of the base plate **204** at a position rearward of the crank plate **322**. The guide plate **328** extends in the left-right direction and the up-down direction. As shown in FIG. **15**, the guide grooves **330**, **332** of the guide plate **328** have a substantially rectangular shape with rounded corners. The guide grooves **330**, **332** define a side-stepping track S shown by a broken line in FIG. **15**. The side-stepping track S has a substantially rectangular shape with rounded corners, and includes upper and lower edges extending along the left-right direction, and right and left edges extending along the up-down direction. The side-stepping track S defined by the guide grooves **330**, **332** is the same as the side-stepping track S defined by the guide grooves **302**, **304**.

(119) In the rear crank mechanism **277**, when the pulleys **308**, **310** rotate, the crank pins **318**, **320** move in a rotating direction of the crank arms **314**, **316** by rotation of the crank arms **314**, **316**. Here, since the rollers **324**, **326** are accommodated in the guide grooves **330**, **332**, the crank pins **318**, **320** move along the side-stepping track S defined by the guide grooves **330**, **332** while sliding inside the long holes **314***b*, **316***b*. Due to this, the crank plate **322** to which the crank pins **318**, **320** are fixed also moves along the side-stepping track S defined by the guide grooves **330**, **332**.

(120) As shown in FIG. **13**, the step bars **272**, **274** have front ends fixed to the crank plate **294** of the front crank mechanism **276**, and war ends fixed to the crank plate **322** of the rear crank

mechanism **277**. Further, the pulley **280** of the front crank mechanism **276** and the pulley **308** of the rear crank mechanism **277** are coupled by the rotation transmitting shaft **285**. Due to this, the pulleys **280**, **282** of the front crank mechanism **276** and the pulleys **308**, **310** of the rear crank mechanism **277** rotate in synchrony with each other, and the crank plate **294** of the front crank mechanism **276** and the crank plate **322** of the rear crank mechanism **277** operate in synchrony. One of the front crank mechanism **276** and the rear crank mechanism **277** (such as the front crank mechanism **276**) is provided with a zero-point detection sensor (not shown). The zero-point detection sensor may for example include a permanent magnet (not shown) fixed to the crank plate **294** and a Hall element (not shown) fixed to the guide plate **300**. The zero-point detection sensor is configured to detect whether the crank plates **294**, **322** are at a zero-point position, where the zero-point position is the center of the upper edge of the side-stepping track S in the left-right direction.
(121) As shown in FIG. **13**, the worm gear casing **283** is arranged rearward of the pulley **282** of the front crank mechanism **276**. The worm gear casing **283** is fixed to the support plate **278** of the front crank mechanism **276**. The gearbox **281** is arranged rightward of the worm gear casing **283** and is fixed to the worm gear casing **283**. The stepper motor **279** is arranged rightward of the gearbox **281** and is supported by the gearbox **281**. The stepper motor **279** may for example be a DC brush motor. The stepper motor **279** is coupled to the pulley **282** via a reduction gear (not shown) incorporated in the gearbox **281** and a worm gear (not shown) incorporated in the worm gear casing **283**. When the stepper motor **279** rotates in a forward direction or a reverse direction, the pulleys **280**, **282**, **308**, **310** thereby rotate in the forward direction or the reverse direction, by which the crank plates **294**, **322** move rightward or leftward along the side-stepping track S, and the step bars **272**, **274** also move rightward or leftward along the side-stepping track S. As shown in FIG. **1**, the base plate **204** includes a through hole **204***b* for avoiding interference with the stepper motor **279**, the gearbox **281**, and the worm gear casing **283**.
(122) As shown in FIG. **17**, in the state in which the crank plates **294**, **322** are located at the upper edge of the side-stepping track S (see FIG. **15**) and the step bars **272**, **274** are lifted up, the crank plates **294**, **322** and the step bars **272**, **274** are separated from the primary rebars R**1** and the secondary rebars R**2**. In this state, since the right crawler **192** and the left crawler **194** are in contact with the primary rebars R**1** and the secondary rebars R**2**, the rebar tying robot **100** drives the right crawler **192** and the left crawler **194** and thus can move in the front-rear diction.
(123) When the stepper motor **279** is rotated from the state shown in FIG. **17**, the crank plates **294**, **322** move along the side-stepping track S (see FIG. **15**), accompanying which the step bars **272**, **274** move downward, and the crank plates **294**, **322** and the step bars **272**, **274** come into contact with the secondary rebars R**2**. When the stepper motor **279** is further rotated from this state, the crank plates **294**, **322** and the step bars **272**, **274** further move downward, as a result of which the right crawler **192** and the left crawler **194** separate from the secondary rebars R**2** as shown in FIG. **18**. By further continuing to rotate the stepper motor **279**, the rebar tying robot **100** moves rightward or leftward by a step width corresponding to a width of the side-stepping track S in the left-right direction, after which the crank plates **294**, **322** and the step bars **272**, **274** move upward, by which the right crawler **192** and the left crawler **194** come into contact again with the primary rebars R**1** and the secondary rebars R**2** and the crank plates **294**, **322** and the step bars **272**, **274** separate from the secondary rebars R**2**. When the zero-point detection sensor detects that the crank plates **294**, **322** have moved to the zero-point position, rotation of the stepper motor **279** stops. As above, by driving the side stepper **196**, the rebar tying robot **100** can move rightward or leftward by a predetermined step width.
(124) The side-stepping track S defined by the guide grooves **302**, **304**, **330**, **332** is not limited to the aforementioned substantially rectangular shape, but may have various other shapes. The shape may be any shape so long as that, upon when the step bars **272**, **274** move along the side-stepping track S, lower ends of the step bars **272**, **274** move to positions lower than the lower ends of the right crawler **192** and the left crawler **194**, and then the lower ends of the step bars **272**, **274** move

in the left-right direction and then the lower ends of the step bars **272**, **274** move to positions higher than the lower ends of the right crawler **192** and the left crawler **194**. For example, the side-stepping track S may be circular, oval, triangular with its bottom edge on the lower side, or polygonal such as pentagon or with more vertices.

(125) As shown in FIG. **11**, the front three-dimensional distance sensor **198** is arranged on a front surface of the front frame **214** at the vicinity of the center of the front frame **214** in the left-right direction. The rear three-dimensional distance sensor **200** is arranged on a rear surface of the rear frame **216** at the vicinity of the center of the rear frame **216** in the left-right direction. The central three-dimensional distance sensor **202** is arranged on the lower surface of the base plate **204** at the vicinity of the center of the left end of the base plate **204** in the front-rear direction. The front three-dimensional distance sensor **198** and the rear three-dimensional distance sensor **200** are directed downward. The central three-dimensional distance sensor **202** is directed diagonally downward toward the right side. The front three-dimensional distance sensor **198**, the rear three-dimensional distance sensor **200**, and the central three-dimensional distance sensor **202** are Time-of Flight (TOF) sensors configured to output point cloud data that represents a three-dimensional position of an object in a field of view using point clouds. The control unit **126** of the rebar tying robot **100** is configured to identify a relative arrangement of each of the primary rebars R**1** and the secondary rebars R**2** relative to each of the front three-dimensional distance sensor **198**, the rear three-dimensional distance sensor **200**, and the central three-dimensional distance sensor **202** based on the point cloud data obtained by the front three-dimensional distance sensor **198**, the rear three-dimensional distance sensor **200**, and the central three-dimensional distance sensor **202**. A field of view of the f ent three-dimensional distance sensor **198** is arranged frontward of a field of view of the central three-dimensional distance sensor **202**, and a field of view of the rear three-dimensional distance sensor **200** is arranged rearward of the field of view of the central three-dimensional distance sensor **202**. Three-dimensional distance sensors that employ stereo vision scheme or pattern projection scheme may be used instead of the TOF sensors as the front three-dimensional distance sensor **198**, the rear threo-dimensional distance sensor **200**, and the central three-dimensional distance sensor **202**.

(126) (Operation of Rebar Tying Robot **100**)

(127) When the user operates the operation execution button **122** and execution of the operation of the rebar tying robot **100** is instructed, the control unit **126** executes processes shown in FIG. **19**, FIG. **20**.

(128) As shown in FIG. **19**, in S**2**, the control unit **126** executes a side step process (see FIG. **2***g*) until the rebar tying robot **100** arrives above a primary rebar R**1**′ that is to be a target of tying work among the plurality of primary rebars R**1**. Details of the side step process will be described later.

(129) In S**4**, the control unit **126** generates a primary rebar model in which a position and an angle of the primary rebar R**1**′ as viewed from the rebar tying robot **100** are modeled by a linear line. Details of a process for generating the primary rebar model will be described later.

(130) In S**6**, the control unit **126** determines whether a position of the primary rebar R**1**′ in the left-right direction is within a first predetermined positional range from a reference position. The reference position hereof refers to a position where an intersecting point of the primary rebar R**1**′ and the secondary rebar R**2** should exist when the operation unit **104** lowers the rebar tying machine **2** to perform tying work. For example, in relation to the front-rear direction and the left-right direction, the reference position is located at the center of the base plate **204** in the front-rear direction and the left-right direction. Further, the position of the primary rebar R**1**′ in the left-right direction hereof refers to the position of the primary mbar R**1**′ in the left-right direction at the same position in the front-rear direction as the reference position. The position of the primary rebar R**1**′ in the left-right direction can be calculated based on the primary rebar model. Further, the first predetermined positional range hereof refers to a range within which the tying work by the rebar tying machine **2** can be executed so long as the position of the primary rebar R**1**′ in the left-right

direction is within the range. In the case where the position of the primary rebar R**1**′ in the left-right direction is not within the first predetermined positional range (case of NO), the process proceeds to S**10**. In the case where the position of the primary rebar R**1**′ in the left-right direction is within the first predetermined positional range (case of YES), the process proceeds to S**8**.

(131) In S**8**, the control unit **126** determines whether the angle of the primary rebar R**1**′ is within a predetermined angle range from a reference angle. The reference angle hereof refers to an angle at which the primary rebar R**1**′ should be oriented with respect to the front-rear direction of the rebar tying robot **100** at the intersecting point of the primary rebar R**1**′ and the secondary rebar R**2** when the operation unit **104** lowers the rebar tying machine **2** to execute the tying work. For example, the reference angle is 0 degrees. The angle of the primary rebar R**1**′ can be calculated based on the primary rebar model. Further, the predetermined angle range hereof is a range within which the tying work by the rebar tying machine **2** can be executed so long as the angle of the primary rebar R**1**′ is within this range. In the case where the angle of the primary rebar R**1**′ is not within the predetermined angle range (case of NO), the process proceeds to S**10**. In the case where the angle of the primary rebut R**1**′ is within the predetermined angle range (case of YES), the process proceeds to S**22** (see FIG. **20**).

(132) In S**10**, the control unit **126** starts rebar tracing control. In the rebar tracing control, the control unit **126** moves the rebar tying robot **100** forward or rearward while providing a speed difference between the right crawler **192** and the left crawler **194**, and thereby brings the position and angle of the primary rebar R**1**′ in the left-right direction closer to the reference position and reference angle. Details of the rebar tracing control will be described later.

(133) In S**12**, the control unit **126** generates a primary rebar model of the primary rebar R**1**′ by a process similar to S**4** in order to update the primary rebar model as the rebar tying robot **100** moves.

(134) In S**14**, the control unit **126** determines whether the position of the primary rebar R**1**′ in the left-right direction is within the first predetermined positional range from the reference position. In the case where the position of the primary rebar R**1**′ in the left-right direction is not within the first predetermined positional range (case of NO), the process returns to S**12**. In the case where the position of the primary rebar R**1**′ in the left-right direction is within the first predetermined range (case of YES), the process proceeds to S**16**.

(135) In S**16**, the control unit **126** determines whether the angle of the primary rebar R**1**′ is within the predetermined angle range from the reference angle. In the case where the angle of the primary rebar R**1**′ is not within the predetermined angle range (case of NO), the process returns to S**12**. In the case where the angle of the primary rebar R**1**′ is within the predetermined angle range (case of YES), the process proceeds to S**18**.

(136) In S**18**, the control unit **126** finishes the rebar tracing control. By performing the processes from S**10** to S**18**, the rebar tying robot **100** moves so that the position and the angle of the primary rebar R**1**′ in the left-right direction comes to match the reference position and the reference angle as shown in FIG. **21**. In FIGS. **21** to **24**, the reference position and the reference angle of the rebar tying robot **100** are represented by a cross-cursor C.

(137) As shown in FIG. **19**, the control unit **126** executes a returning process in S**20**. In the returning process, the control unit **126** moves the rebar tying robot **100** in a reverse direction opposite from the direction in which the rebar tying robot **100** moved in the preceding processes of S**10** to S**18**. In doing so, the control unit **126** moves the rebar tying robot **100** by providing a speed difference between the right crawler **192** and the left crawler **194** so that the position and angle of the primary rebar R**1**′ in the left-right direction that were brought to be within the first predetermined positional range and the predetermined angular range in the preceding processes of S**10** to S**18** do not deviate out of the first predetermined positional range and the predetermined angular range. The control unit **126** measures a moving distance of the rebar tying robot **100** in the forward or rearward direction from the time when the rebar tracing control was started in S**10** until

the rebar tracing control is finished in S**18**, and moves the rebar tying robot **100** in the reverse direction over the same moving distance in the returning process of S**20**. By performing the returning process of S**20**, the rebar tying robot **100** moves in the reverse direction as shown in FIG. **22** while the position and angle of the primary rebar R**1**′ in the left-right direction are matched to the reference position and reference angle.
(138) As shown in FIG. **20**, in S**22**, the control unit **126** starts the rebar tracing control similar to S**10** (see FIG. **19**). Due to this, the rebar tying robot **100** starts to move forward or rearward along the primary rebar R**1**′.
(139) In S**24**, the control unit **126** generates a primary rebar model related to the primary rebar R**1**′ by a process similar to S**4** so as to update the primary rebar model in accordance with the movement of the rebar tying robot **100**.
(140) In S**26**, the control unit **126** identifies a position of the intersecting point of the primary rebar R**1**′ and the secondary rebar R**2**. Details of a position identification process for the intersecting point will be described later.
(141) In S**28**, the control unit **126** determines whether the position of the intersecting point of the primary rebar R**1**′ and the secondary rebar R**2** is within a second positional range from the reference position. The second positional range hereof is a range within which the tying work by the rebar tying machine **2** can be executed so long as the position of the intersecting point of the primary rebar R**1**′ and the secondary rebar R**2** is within the range. In the case where the position of the intersecting point is not within the second positional range (case of NO), the process returns to S**24**. In the case where the position of the intersecting point is within the second positional range (case of YES), the process proceeds to S**30**.
(142) In S**30**, the control unit **126** finishes the rebar tracing control. Due to this, the rebar tying robot **100** stops moving forward or rearward along the primary rebar R**1**′.
(143) In S**32**, the control unit **126** executes a rebar tying process. In the rebar tying process, the control unit **126** drives the lift mechanism **130** to lower the rebar tying machine **2** to set the rebar tying machine **2** at the intersecting point of the primary rebar R**1**′ and the secondary rebar R**2**, and drives the grip mechanism **132** to perform the tying work using the rebar tying machine **2** on the primary rebar R**1**′ and the secondary rebar R**2**. After this, the control unit **126** drives the lift mechanism **130** to lift the rebar tying machine **2**. After S**32**, the process proceeds to S**34**.
(144) In S**34**, the control unit **126** determines whether the tying work performed in S**32** has been completed normally. In the case it is determined that the tying work has not been completed normally (case of NO), the process returns to S**32**. In the case it is determined that the tying work has been completed normally (case of YES), the process proceeds to S**36**.
(145) In S**36**, the control unit **126** determines whether all the tying work for the primary rebar R**1**′ has been completed. When it is determined that it has not yet been completed (case of NO), the process returns to S**22**. By repeating the processes from S**22** to S**36**, the rebar tying robot **100** repeatedly performs the tying work on the intersecting points of the primary rebar R**1**′ and the secondary rebars R**2** while moving along the primary rebar R**1**′ as shown in FIG. **23**.
(146) As shown in FIG. **20**, when it is determined that all the tying work for the primary rebar R**1**′ has been completed in S**36** (when it is determined YES), the process proceeds to S**38**.
(147) In S**38**, the control unit **126** determines whether the lying work has been completed for all of the primary rebars R**1**. When it is determined that it has not yet been completed (case of NO), the process proceeds to S**40**.
(148) In S**40**, the control unit **126** changes the primary rebar R**1**′ that is to be the target of the tying work to another primary rebar R**1** for which the tying work has not been completed. After S**40**, the process returns to S**2** (see FIG. **19**).
(149) In S**38**, when it is determined that the tying work has been completed for all of the primary rebars R**1** (case of YES), the processes of FIOS. **19** and **20** are terminated.
(150) In the processes of FIGS. **19** and **20**, when the rebar tying robot **100** repeatedly performs the

tying work on the intersecting points of the primary rebar R**1**′ and the secondary rebars R**2**, every other intersecting point of the primary rebar R**1**′ and the secondary rebars R**2** may be tied. In this case, the intersecting points which the rebar tying robot **100** targets for the tying work may be selected so that at least one of each pair of adjacent intersecting points is tied as the result of the repeated tying work.
(151) (Rebar Tracing Control)
(152) When the rebar tying robot **100** is to be moved, the control unit **126** determines a moving speed vR(t) of the right crawler **192** and a moving speed vL(t) of the left crawler **194**, and rotates the right crawler motor **228** at a rotary speed corresponding to the moving speed vR(t) of the right crawler **192** and rotates the left crawler motor **254** at a rotary speed corresponding to the moving speed vL(t) of the left crawler **194**. As shown in FIG. **24**, a moving velocity v(t) in the forward direction and an angular velocity ω(t) of rotation about the op-down direction of the rebar tying robot **100** realized in this case are respectively given by the following equations:
(153) $v(t) = (\mathrm{vR}(t) + \mathrm{vL}(t)) / 2$ (1) $(t) = (\mathrm{vR}(t) - \mathrm{vL}(t)) / 21$ (2)
(154) where 2l is a distance between the right crawler **192** and the left crawler **194**.
(155) In the rebar tracing control executed in the processes of FIGS. **19** and **20**, the control unit **126** determines vR(t) and vL(t) such that the reference position and reference angle of the rebar tying robot **100** become closer to the position and angle of the primary rebar R**1**′ in the left-right direction. Specifically, the control unit **126** calculates vR(t) and vL(t) respectively in the following equations:
(156) $\mathrm{vR}(t) = \mathrm{vconst} + \quad v(t)$ (3) $\mathrm{vL}(t) = \mathrm{vconst} - \quad v(t)$ (4)
(157) where vconst is a constant value and Δv(t) is a correction amount for bringing the reference position and reference angle of the rebar tying robot **100** closer to the position and angle of the primary rebar R**1**′ in the left-right direction.
(158) When vR(t) and vL(t) are given by the above equations (3), (4), the velocity v(t) and the angular velocity ω(t) realized by the rebar tying robot **100** are represented by the following equations:
(159) $v(t) = \mathrm{vconst}$ (5) $(t) = \quad v(t) / 1$ (6)
(160) As shown in FIG. **24**, when the position of the primary rebar R**1**′ in the left-right direction (amount of displacement from the reference position) is e(t) and the angle of the primary rebar R**1**′ (amount of displacement from the reference angle) is θ(t), the control unit **126** calculates the correction amount Δv(t) by the following equation:
(161) $\quad v(t) = k1 \times e(t) + k2 \times e'(t) + k3 \times \quad (t) + k4 \times \quad '(t)$ (7)
(162) where e′(t) is a time differential value of e(t), θ′(t) is a time differential value of θ(t), and each of k**1**, k**2**, k**3**, and k**4** is a positive fixed number.
(163) As it is apparent from FIG. **24**, if an angular velocity ω(t)(=Δv(t)/l) is given when the rebar tying robot **100** moves forward at a speed v, e(t) and θ(t) both approach zero as the rebar tying robot **100** moves forward. Due to this, by giving the correction amount Δv(t) as in the above equation (7), the reference position and reference angle of the rebar tying robot **100** can be brought closer to the position and angle of the primary rebar R**1**′ in the left-right direction.
(164) FIG. **25** shows as an example a trajectory of the rebar tying robot **100** moving forward by the rebar tracing control in the case where a predetermined amount of displacement is present between the reference position of the rebar tying robot **100** and the position of the primary rebar R**1**′ in the left-right direction. In FIGS. **25** to **27**, d**1**[mm] indicates positions in a direction along the primary rebar R**1**′ and d**2**[mm] indicates positions in a direction perpendicular to the direction along the primary rebar R**1**′. As shown in FIG. **23**, by executing the rear tracing control, the amount of displacement between the reference position of the rebar tying robot **100** and the position of the primary rebar R**1**′ in the left-right direction is resolved, and the rebar tying robot **100** can move along the primary rebar R**1**′.

(165) FIG. **26** shows as another example a trajectory of the rebar tying robot **100** moving forward when the right crawler **192** operates normally but the left crawler **194** slips. When the left crawler **194** slips, an actual moving speed of the left crawler **194** becomes slower, thus as shown in FIG. **26**, the rebar tying robot **100** gradually deviates away from the primary rebar R**1**′ toward the left side as the rebar tying robot **100** moves forward should no rebar tracing control be executed. Unlike this case, when the rebar tracing control is executed, the correction amount Δv(t) is given to bring the reference position and reference angle of the rebar tying robot **100** closer to the position and angle of the primary rebar R**1**′ in the left-right direction even if the left crawler **194** is slipping, thus the rebar tying robot **100** does not separate away from the primary rebar R**1**′ and can move forward along the primary rebar R**1**′.
(166) When vR(t) and vL(t) are given by the above equations (3) and (4), vR(t) and vL(t) may take values exceeding vconst. Due to this, it is necessary to prepare motors capable of high-speed operation as the right crawler motor **228** and the left crawler motor **254**, which may adversely increases the size and weight of the right crawler motor **228** and the left crawler motor **254**.
(167) As such, vR(t) and vL(t) may be given as follows instead of the above equations (3) and (4). That is, after Δv is calculated by the above equation (7), the following may be used when Δv≥0:
(168) $\mathrm{vR}(t) = \mathrm{vconst} \quad (8) \quad \mathrm{vL}(t) = \mathrm{vconst} - 2 \quad v(t) \quad (9)$ andif $v < 0$;

$\mathrm{vR}(t) = \mathrm{vconst} + 2 \quad v(t) \quad (10) \quad \mathrm{vL}(t) = \mathrm{vconst} \quad (11)$

(169) When vR(t) and vL(t) are given by the above equations (8), (9), (10). (11), vR(t) and vL(t) will never exceed vconst, thus motors that can rotate at vconst may be prepared as the right crawler motor **228** and the left crawler motor **254**, and the sizes and weights of the right crawler motor **228** and the left crawler motor **234** can be suppressed from increasing.
(170) When vR(t) and vL(t) are given by the above equations (8), (9), (10), (11), the velocity v(t) and angular velocity ω(t) realized by the rebar tying robot **100** are expressed in the following equations:
(171) $v(t) = \mathrm{vconst} -$ .Math. v .Math. (12)

(172) That is, when vR(t) and vL(t) are determined by the above equations (8), (9), (10), (11), the moving velocity v(t) of the rebar tying robot **100** in the forward direction decreases by |Δ| from vconst. Due to this, |Δv| becomes greater than vconst, the rebar tying robot **100** starts to move not forward but rearward.
(173) As such, in the present embodiment, upper and lower limits are given to Δv(t) as in the following equation:
(174) .Math. $v(t)$ .Math. $< k \times$ vconstwhere$0 < k \leq 1$. (14)

(175) FIG. **27** shows trajectories of the rebar tying robot **100** in the case where vR(t) and vL(t) are given using the equations (3) and (4) (indicated as speed increase+decrease in FIG. **27**) and the case where vR(t) and vL(t) are given using the equations (8), (9), (10), (11), and (14) (indicated as speed decrease only in FIG. **27**). As shown in FIG. **27**, when vR(t) and vL(t) are given by the equations (8), (9), (10), (11), and (14), the trajectory of the rebar tying robot **100** approaches the primary rebar R**1**′ at a faster pace when the value of k in the equation (14) is set larger. However, when the value of k becomes excessively large, overshoot occurs and convergence of the trajectory of the rebar tying robot **100** is delayed. Due to this, when vR(t) and vL(t) are given using the equations (8), (9), (10), (11), and (14), it is possible to promptly bring the trajectory of the rebar tying robot **100** closer to the primary rebar R**1**′ by setting k=0.8, for example.
(176) (Side Step Process)
(177) In the side step process shown in S**2** of FIG. **19**, the control unit **126** executes processes shown in FIG. **28**. In the following explanation, the rightward direction is termed X direction, the frontward direction is termed Y direction, and the upward direction is termed Z direction with the rebar tying robot **100** as the reference, and the reference position of the rebar tying robot **100** is expressed as X**0**, Y**0**, Z**0**.

(178) In S**52**, the control unit **126** obtains point cloud data from the front three-dimensional distance sensor **198**. In the following explanation, the point cloud data obtained from the front three-dimensional distance sensor **198** may be termed front point cloud data.
(179) In S**54**, the control unit **126** extracts, from the point clouds included in the front point cloud data, point clouds located at positions in the Z direction corresponding to the primary rebar R**1**′ and the secondary rebars R**2**. Specifically, the control unit **126** extracts, from the point clouds included in the front point cloud data, the point clouds whose positions in the Z direction are within a predetermined rebar depth range (for example, a range whose upper end is defined by a position in the Z direction of lower surfaces of the right crawler **192** and the left crawler **194** and whose lower end is defined by a position in the Z direction that is located below the upper end by a sum of a diameter of the primary rebar R**1** and a diameter of the secondary rebar R**2**). The front point cloud data obtained in S**52** includes point clouds corresponding to the primary rebar R**1**′ and the secondary rebars R**2** as well as point clouds corresponding to, for example, the ground surface located lower than the primary rebar R**1**′ and the secondary rebars R**2**. By executing the process of S**54**, the point clouds corresponding to the ground surface can be excluded and only the point clouds which are highly likely to correspond to the primary rebar R**1**′ and the secondary rebars R**2** can be extracted.
(180) In S**56**, the control unit **126** clusters the point clouds extracted in S**54**, identifies a cluster with the largest number of point clouds as a rebar cluster, and extracts the point clouds included in the rebar cluster. Clustering of the point clouds is executed by, when for example a distance between points is included in a range that is a predetermined value or less, associating the points included in the point clouds to each other so that those points are included in the same cluster.
(181) In S**58**, the control unit **126** extracts only the point clouds that are within a predetermined judgement area from the point clouds included in the rebar cluster identified in S**56**. The judgement area is set for example as an area within a predetermined distance from the reference position X**0** of the rebar tying robot **100** in the X direction (for example, when ΔX**0** is set as 1.5 times the diameter of the primary rebar R**1**′, the area ranges from X**0**+ΔX**0** to X**0**−ΔX**0**). Due to this, as shown in FIG. **29**, only the point clouds PG**2** that are within the judgement area are extracted (see FIG. **30**) from the point clouds PG**1** included in the rebar cluster. In FIGS. **29**, **30**, **33**, **34**, **35**, **36**, **38**, and **39**, it should be noted that the point clouds are depicted as a hatched region, and each point constituting the point clouds is not depicted.
(182) As shown in FIG. **28**, in S**60**, the control unit **126** determines whether the number of point clouds within a confirmation area among the point clouds extracted in SSS is equal to or greater than a predetermined threshold. As shown in FIG. **30**, the confirmation area DR is an area that is the same as the judgement area used in S**58** in the X direction, and is an area having a predetermined length (such as 1 mm) in the Y direction. As shown in FIG. **30**, in the present embodiment, a plurality of confirmation areas DR whose positions in the X direction are different is set. As shown in FIG. **28**, in the case where the number of point clouds in the confirmation area does not reach the threshold in S**60** (case of NO), the control unit **126** determines that the front portion of the rebar tying robot **100** is not positioned above the primary rebar R**1**′ and the process proceeds to S**72**. In the case where the number of point clouds in the confirmation area is equal to or greater than the threshold (case of YES), the control unit **126** determines that the front portion of the rebar tying robot **100** is located above the primary rebar R**1**′ and the process proceeds to S**62**.
(183) In S**62**, the control unit **126** obtains point cloud data from the rear three-dimensional distance sensor **200**. In the following explanation, the point cloud data obtained from the rear three-dimensional distance sensor **200** may be termed rear point cloud data.
(184) In S**64**, similar to S**54**, the control unit **126** extracts, from the point clouds included in the rear point cloud data, point clouds located at positions in the Z direction corresponding to the primary rebar R**1**′ and the secondary rebars R**2**.
(185) In S**66**, similar to S**56**, the control unit **126** clusters the point clouds extracted in S**64**,

identifies a cluster with the largest number of point clouds as a rebar cluster, and extracts the point clouds included in the rebar cluster.
(186) In S**68**, similar to S**58**, the control unit **126** extracts only the point clouds that are within the predetermined judgement area from the point clouds included in the rebar cluster identified in S**56**.
(187) In S**70**, similar to S**60**, the control unit **126** determines whether the number of point clouds within confirmation area among the point clouds extracted in S**58** is equal to or greater than the predetermined threshold. In the case where the number of point clouds in the confirmation area does not reach the threshold (case of NO), the control unit **126** determines that the rear portion of the rebar tying robot **100** is not positioned above the primary rebar R**1**′ and the process proceeds to S**72**.
(188) In S**72**, the control unit **126** drives the side stepper **196** to move the rebar tying robot **100** rightward or leftward. After S**72**, the process returns to S**52**.
(189) In S**70**, in the case where the number of point clouds in the confirmation area is equal to or greater than the threshold (case of YES), the control unit **126** determines that the front portion of the rebar tying robot **100** is located above the primary rebar R**1**′. In this case, both the front and rear portions of the rebar tying robot **100** are located above the primary rebar R**1**′, and there is no further need to move the rebar tying robot **100** in the left-right direction, thus the control unit **126** terminates the process of FIG. **23**.
(190) According to the process of FIG. **28**, the control unit **126** can determine whether the side step motion of the rebar tying robot **100** has been completed by using processes with a relatively small computation load.
(191) (Primary Rebar Model Generation Process executed by Control Unit **126**)
(192) In the primary rebar model generation process indicated in S**4** and S**12** of FIG. **19** and S**24** of FIG. **20**, the control unit **126** executes processes indicated in FIGS. **31** and **32**.
(193) As shown in FIG. **31**, in S**82**, the control unit **126** obtains front point cloud data from the front three-dimensional distance sensor **198**.
(194) In S**84**, the control unit **126** extracts, from the point clouds included in the front point cloud data, the point clouds whose positions in the Z-direction are within a predetermined rebar depth range.
(195) In S**86**, the control unit **126** clusters the point clouds extracted in S**84**, identifies a cluster with the largest number of point clouds as a rebar cluster, and extracts the point clouds included in the rebar cluster.
(196) In S**88**, the control unit **126** identifies a maximum value Xmax and a minimum value Xmin of positions in the X direction of the point clouds included in the rebar cluster identified in S**86**.
(197) In S**90**, the control unit **126** determines whether a difference between Xmax and Xmin identified in S**88** is equal to or greater than a predetermined value (such as 3 times the diameter of the primary rebar R**1**′). In the case where the difference between Xmax and Xmin does not reach the predetermined value (case of NO), the control unit **126** determines that the rebar cluster identified in S**86** does not include point clouds corresponding to the secondary rebar R**2**, and the process proceeds to S**102**. In the case where the difference between Xmax and Xmin is equal to or greater than the predetermined value (case of YES), the control unit **126** determines that the point clouds corresponding to the secondary rebar R**2** are included in the rebar cluster identified in S**86**, and the process proceeds to S**92**.
(198) In S**92**, the control unit **126** identifies a maximum value Ymax**1** and a minimum value Ymin**1** of positions in the Y direction of the point clouds, which am included in the rebar cluster identified in S**86** and whose positions in the X direction are close to Xmax.
(199) In S**94**, the control unit **126** identifies a maximum value Ymax**2** and a minimum value Ymin**2** of positions in the Y direction of the point clouds, which are included in the rebar cluster identified in S**86** and whose positions in the X direction are close to Xmin.
(200) In S**96**, the control unit **126** extracts, from the point clouds included in the rebar cluster

identified in S**86**, only the point clouds that are within a predetermined secondary rebar candidate area. The secondary rebar candidate area is for example set to an area ranging from Xmax to Xmin in the X direction and ranging from the larger one of Ymax**1** and Ymax**2** to the smaller one of Ymin**1** and Ymin**2** in the Y direction. Due to this, as shown in FIG. **33**, only the point clouds PG**2** that are within the secondary rebar candidate area am extracted from the point clouds PG**1** included in the rebar cluster (see FIG. **34**).
(201) In S**98**, the control unit **126** generates a secondary rebar model in which a position and an angle of a secondary rebar R**2** as viewed from the rebar tying robot **100** are modeled by a linear line, according to a Random Sample Consensus (RANSAC) method based on the point clouds extracted in S**96**. Details of rebar model generation by the RANSAC method will be described later. As shown in FIG. **34**, the secondary rebar model RM**2** is generated according to the above based on the point clouds PG**2** within the secondary rebar candidate area.
(202) In S**100**, the control unit **126** removes point clouds that are located at or in the vicinity of the secondary rebar model generated in S**98** from the point clouds included in the rebar cluster identified in S**86**, and extracts remaining point clouds. The point clouds located at or in the vicinity of the secondary rebar model hereof refer to the point clouds whose distance from the secondary rebar model in a direction perpendicular to the secondary rebar model is smaller than a predetermined value (for example, 1 times the diameter of the secondary rebars R**2**). According to the above, as shown in FIG. **35**, point clouds PG**3** obtained by removing the point clouds located at or in the vicinity of the secondary rebar model RM**2** from the point clouds PG**1** included in the rebar cluster are extracted (see FIG. **36**).
(203) In S**102**, the control unit **126** generates a tentative primary rebar model using the RANSAC method based on the point clouds extracted in S**100** (or in the case of NO in S**90**, the point clouds included in the rebar cluster identified in S**86**). Due to this, as shown in FIG. **36**, the tentative primary rebar model TRM**1** is generated from the point clouds PG**3**.
(204) In S**104**, the control unit **126** extracts, from the point clouds extracted in S**100**, the point clouds used in generating the tentative primary rebar model TRM**1** in S**102** (that is, the point clouds that were not determined as outliers in the RANSAC method) as point clouds being a candidate of the primary rebar R**1**′. The point clouds extracted in S**104** may hereinbelow be termed front primary rebar candidate point clouds.
(205) Next, as shown in FIG. **32**, in S**106**, the control unit **126** obtains rear point cloud data from the rear three-dimensional distance sensor **200**.
(206) Processes from S**108** to S**128** executed in connection to the rear point cloud data are the same as the processes of S**84** to S**104** executed in connection to the front point cloud data, thus the explanation thereof will be omitted. Point clouds extracted in S**128** may hereinbelow be termed rear primary rebar candidate point clouds.
(207) In S**130**, a primary rebar model is generated using a least square method based on the front primary rebar candidate point clouds obtained in S**104** and the rear primary rebar candidate point clouds obtained in S**128**. When the primary rebar model is generated in S**130**, the processes of FIGS. **28** and **29** are terminated.
(208) In the process of S**130**, the primary rebar model may be generated using the RANSAC method instead of the least square method. However, when the RANSAC method is used, it there is a difference in the number of the front primary rebar candidate point clouds and the number of the rear primary rebar candidate point clouds, the primary rebar candidate point clouds having the smaller number could be handled as outliers, and they may not be used in generating the primary rebar model. As above, by generating the primary rebar model using the least square method, a more accurate primary rebar model can be obtained.
(209) (Intersecting Position Identification Process Executed by Control Unit **126**)
(210) In the intersecting position identification process indicated in S**26** of FIG. **20**, the control unit **126** executes processes shown in FIG. **37**.

(211) In S**142**, the control unit **126** obtains point cloud data from the central three-dimensional distance sensor **202**. In the following explanation, the point cloud data obtained from the central three-dimensional distance sensor **202** may be termed central point cloud data.
(212) In S**144**, the control unit **126** extracts point clouds whose positions in the Z direction are within the predetermined rebar depth range from the point clouds included in the central point cloud data.
(213) In S**146**, the control unit **126** clusters the point clouds extracted in S**144**, identifies a cluster with the largest number of point clouds as a rebar cluster, and extracts the point clouds included in the rebar cluster.
(214) In S**148**, the control unit **126** removes point clouds that are located at or in the vicinity of the primary rebar model generated in S**24** (see FIG. **20**) from the point clouds included in the rebar cluster identified in S**146**, and extracts remaining point clouds. The point clouds located at or in the vicinity of the primary rebar model hereof refer for example to the point clouds whose distance from the primary rebar model in a direction perpendicular to the primary rebar model is smaller than a predetermined value (for example, 1 times the diameter of the primary rebar R**1**′). According to the above, as shown in FIG. **38**, point clouds PG**2** obtained by removing the point clouds located at or in the vicinity of the primary rebar model RM**1** from the point clouds PG**1** included in the rebar cluster are extracted (see FIG. **39**).
(215) In S**150**, the control unit **126** determines whether the number of the point clouds extracted in S**148** is equal to or greater than a predetermined number. When the number of the point clouds does not reach the predetermined number (case of NO), the control unit **126** determines that the intersecting point of the primary rebar R**1**′ and the secondary rebar R**2** is not present within the field of view of the central three-dimensional distance sensor **202**. In this case, the process of FIG. **30** is terminated without the control unit **126** identifying the position of the intersecting point. In the case where the number of the point clouds is equal to or greater than the predetermined number in S**150** (case of YES), the process proceeds to S**152**.
(216) In S**152**, the control unit **126** identifies Yc, which is a position in the Y direction of the intersecting point of the primary rebar R**1**′ and the secondary rebar R**2**, based on the point clouds extracted in S**148**. For example, Yc is calculated as an average value Ymean of the positions in the Y-direction of the point clouds extracted in S**148**.
(217) In S**154**, the control unit **126** identifies Xc, which is a position in the X direction of the intersecting point of the primary rebar R**1**′ and the secondary rebar R**2**, based on the primary rebar model generated in S**24** (see FIG. **20**) and Yc identified in S**152**. For example, Xc is identified as a position in the X direction of a point on the primary rebar model when a position in the Y direction is Yc. According to the above, as shown in FIG. **39**, the position Xc, Yc of the intersecting point of the primary rebar R**1**′ and the secondary rebar R**2** is identified. After S**154**, the process of FIG. **30** is terminated.
(218) In the process of S**152**, Yc may be identified by the least square method instead of calculating the average value Ymean of the positions in the Y direction. In this case, Yc can be identified by assuming a linear line perpendicular to a linear line represented by the primary rebar model as the secondary rebar model and calculating an intersecting point of the primary rebar model and the secondary rebar model by the least square method based on the point clouds extracted in S**150**. However, as described above, by identifying Yc by calculating the average value Ymean of the positions in the Y direction, the load of the processes which the control unit **126** executes can be reduced.
(219) (Generation of Rebar Model Using RANSAC Method)
(220) As described above, in the present embodiment, the control unit **126** estimates a correct linear model (tentative primary rebar model, secondary rebar model, and the like) from the point clouds including the outliers according to the RANSAC method, which is one of robust estimation algorithms.

(221) Firstly, as shown in FIG. **40**, the control unit **126** randomly extracts two or more points (such as P**1** and P**2**) as modeling reference points from the point clouds.
(222) Then, as shown in FIG. **41**, the control unit **126** estimates a linear model (such as L**1**) using the least square method, for example, based on the extracted modeling reference points P**1**, P**2**. Further, the control unit **126** counts the number of outliers obtained when the estimated linear model L**1** is applied to the original point clouds. In an example shown in FIG. **41**, among the original point clouds, the number of points whose distance from the estimated linear model L**1** is equal to or greater than a predetermined value (points within the hatched area in the figure) is counted as the number of outliers.
(223) Further, as shown in FIG. **42**, the control unit **126** repeatedly executes random extraction of the modeling reference points and the linear model estimation as described above, and selects candidates of a correct linear model. In the example shown in FIG. **42**, linear models L**1**, L**2** are excluded from the candidates because they have a large number of outliers, and the linear models L**3**, L**4** are selected as the candidates because they have a small number of outliers. Further, the control unit **126** estimates, from the correct linear model candidates L**3**, L**4**, a linear model with less error with respect to the original point clouds (excluding the outliers) as the correct linear model. In the example shown in FIG. **42**, among the linear models L**3**, L**4**, the linear model **14** with less error with respect to the original point clouds that excluded the outliers is estimated as the correct linear model.
(224) (Variants)
(225) In the above embodiment, the configuration in which the reel **10** is attached to the rebar tying machine **2** and the rebar tying machine **2** ties the rebars R using the wire W fed out from the reel **10** was described. Unlike this configuration, a configuration in which a wire supplying unit (not shown) including a large-sized reel (not shown) is mounted on the conveying unit **106** of the rebar tying robot **10** and the rebar tying machine **2** ties the rebars R using the wire W supplied from the wire supplying unit may be employed.
(226) In the above embodiment, the case in which a commercial rebar tying machine **2** (such as TR180D sold by Makita Corporation) is detachably attached to the rebar tying robot **100** was described. Unlike this configuration, the rebar tying robot **100** may be configured with a dedicated rebar tying unit (not shown) integrally attached thereto. In this case, the rebar tying unit may be integrated with the operation unit **104**.
(227) In the above embodiment, an emergency stop button (not shown) for allowing the user to perform emergency stop on the operation of the rebar tying robot **100** may be disposed on the rebar tying robot **100** (such as on the housing **110** of the power supply unit **102**). In this case, when the emergency stop button is pressed by the user, the control unit **126** stops the right crawler motor **228**, the left crawler motor **254**, the stepper motor **279**, and the lift motor **148** and turns off the actuator **180**. When the user presses the operation execution button **122** again after having resolved the risk, the control unit **126** firstly drives the stepper motor **279** to return the front crank mechanism **276** and the rear crank mechanism **277** to the zero-point position, and drives the unit motor **148** to return the lift mechanism **130** to the upper limit position. After this, the control unit **126** executes the normal control and operates the rebar tying robot **100**. The emergency stop button may be arranged at the vicinity of an outer circumference of the rebar tying robot **100**, such as at the vicinity of its end portion along the front-rear direction or left-right direction so that the user can easily press the button in emergency. Further, there may be multiple emergency stop buttons.
(228) In the above embodiment, an operation displaying indicator (not shown) that displays the operating state of the rebar tying robot **100** may be arranged on the rebar tying robot **100** (such as on the housing **110** of the power supply unit **102**). In this case, the operation displaying indicator may display the state of the tying work which the rebar tying robot **100** performs. The state of the tying work may for example include a state of tying all the intersecting points between the primary rebar R**1** and the secondary rebars R**2** and a state of tying every other intersecting point between

the primary rebar R**1** and the secondary rebars R**2**. Alternatively, the operation displaying indicator may show the user a state in which the rebar tying robot **100** has stopped due to error. The operation displaying indicator may display the operating state of the rebar tying robot **100** by colors of emitted light or blinking patterns of one or more light emitting units, or by a combination thereof, for example. In arranging the operation displaying indicator on the housing **110**, the operation displaying indicator may be arranged at a high position so that it is visible from a distance.

(229) In the above embodiment, the configuration in which the conveying unit **106** of the rebar tying robot **100** comprises the right crawler **192** and the left crawler **194** as its longitudinal movement mechanism configured to move the rebar tying robot **100** in the front-rear direction was described. Unlike this configuration, the conveying unit **106** of the rebar tying robot **100** may comprise other types of longitudinal movement mechanism.

(230) In the above embodiment, the configuration in which the conveying unit **106** of the rebar tying robot **100** comprises the side stepper **196** as its lateral movement mechanism configured to move the rebar tying robot **100** in the left-right direction was described. Unlike this configuration, the conveying unit **106** of the rebar tying robot **100** may comprise other types of lateral movement mechanism.

(231) As above, in one or more embodiments, the rebar tying robot **100** is configured to alternately and repeatedly perform the operation of moving, in the direction in which the plurality of primary rebars R**1** extends, over the plurality of primary rebars R**1** and the plurality of secondary rebars R**2** intersecting the plurality of primary rebars R**1** and the operation of tying the plurality of primary rebars R**1** and the plurality of secondary rebars R**2** at points where they intersect. The rebar tying robot **100** comprises the rebar tying machine **2** (an example of rebar tying unit), the conveying unit **106** configured to convey the rebar tying machine **2**, and the control unit **126** configured to control the operation of the conveying unit **106**. The conveying unit **106** comprises the right crawler **192** and the left crawler **194** (examples of longitudinal movement mechanism) configured to move the rebar tying robot **100** in the front-rear direction, and the front three-dimensional distance sensor **198** (an example of first three-dimensional distance sensory configured to output the front point cloud data (an example of first point cloud data) which represents the three-dimensional position of an object in the first field of view by point clouds. The control unit **126** is configured to execute the first rebar extraction process (see S**82**, S**84** of FIG. **31**) in which the control unit **126** extracts, from the point clouds included in the front point cloud data, the point clouds whose positions in the up-down direction are within the predetermined rebar depth range, and the rebar model generation process (see S**98**, S**102** of FIG. **31**, S**130** of FIG. **32**) in which the control unit **126** generates the rebar model in which the primary rebar R**1** or the secondary rebar R**2** is modeled by a linear line based on the point clouds extracted in the first rebar extraction process.

(232) In one or more embodiments, the control unit **126** is configured to execute the cluster extraction process (see S**86** of FIG. **31**) in which the control unit **126** further extracts, from the point clouds extracted in the first rebar extraction process, the point clouds included in the largest cluster. The rebar model generation process is based on the point clouds extracted in the cluster extraction process (see S**98**, **8102** of FIG. **31**, S**130** of FIG. **32**).

(233) In one or more embodiments, the rebar model generation process includes the secondary rebar model generation process (see S**98** of FIG. **31**) in which the control unit **126** generates the secondary rebar model in which the secondary rebar R**2** is modeled based on the point clouds extracted in the first rebar extraction process, the secondary rebar exclusion process (see S**100** of FIG. **31**) in which the control unit **126** further extracts, from the point clouds extracted in the first rebar extraction process, the point clouds that are not included in the area at or in the vicinity of the secondary rebar model, and the primary rebar model generation process (see S**102** of FIG. **31**, S**130** of FIG. **32**) in which the control unit **126** generates the primary rebar model in which the primary rebar R**1** is modeled based on the point clouds extracted in the secondary bar exclusion process.

(234) In one or more embodiments, the rebar model generation process further includes the secondary rebar extraction process (see S**96** of FIG. **31**) in which the control unit **126** further extracts, from the point clouds extracted in the first rebar extraction process, the point clouds that are within the secondary rebar candidate area the secondary rebar candidate area being defined based on the positions of the point clouds located at or in the vicinity of the opposite ends in the left-right direction. The secondary rebar model generation process is based on the point clouds extracted in the secondary rebar extraction process (see S**96**, S**98** of FIG. **31**).
(235) In one or more embodiments, in the secondary rebar model generation process, the secondary rebar model is generated according to the RANSAC method (see S**98** of FIG. **31**).
(236) In one or more embodiments, the front three-dimensional distance sensor **198** is directed downward.
(237) In one or more embodiments, the conveying unit **106** further comprises the rear three-dimensional distance sensor **200** (example of second three-dimensional distance sensor) configured to output the rear point cloud data (example of second point cloud data) which represents the three-dimensional position of the object in the second field of view by the point clouds, the second field of view being rearward of the first field of view. The control unit **126** is configured to further execute the second rebar extraction process (see S**106**, S**108** of FIG. **32**) in which the control unit **126** extracts, from the point clouds included in the rear point cloud data, the point clouds whose positions in the up-down direction are within the rebar depth range. The rebar model generation process is also based on the point clouds extracted in the second rebar extraction process see S**130** of FIG. **32**).
(238) In one or more embodiments, the rebar model generation process includes the first secondary rebar model generation process (see S**98** of FIG. **31**) in which the control unit **126** generates the secondary rebar model in which the secondary rebar R**2** is modeled based on the point clouds extracted in the first rebar extraction process, the first secondary rebar exclusion process (see S**100** of FIG. **31**) in which the control unit **126** further extracts, from the point clouds extracted in the first rebar extraction process, the point clouds that are not included in the area at or in the vicinity of the secondary rebar model generated in the first secondary rebar model generation process, the second secondary rebar model generation process (see S**122** of FIG. **32**) in which the control unit **126** generates the secondary rebar model in which the secondary rebar R**2** is modeled based on the point clouds extracted in the second rebar extraction process, the second secondary rebar exclusion process (see S**124** of FIG. **32**) in which the control unit **126** further extracts, from the point clouds extracted in the second rebar extraction process, the point clouds that are not included in the area at or in the vicinity of the secondary rebar model generated in the second secondary rebar model generation process, and the primary rebar model generation process (see S**130** of FIG. **32**) in which the control unit **126** generates the primary rebar model in which the primary rebar R**1** is modeled based on the point clouds extracted in the first secondary rebar exclusion process and the point clouds extracted in the second secondary rebar exclusion process.
(239) In one or more embodiments, in the primary rebar model generation process, the primary rebar model is generated according to the least square method (see S**130** of FIG. **32**).
(240) In one or more embodiments, the front three-dimensional distance sensor **198** and the rear three-dimensional distance sensor **200** are directed downward.

Claims

1. A rebar tying robot configured to alternately and repeatedly perform an operation of moving, in a direction in which a plurality of primary rebars extends, over the plurality of primary rebars and a plurality of secondary rebars intersecting the plurality of primary rebars and an operation of tying the plurality of primary rebars and the plurality of secondary rebars at points where the plurality of primary rebars and the plurality of secondary rebars intersect, the rebar tying robot comprising: a

rebar tying unit; a conveying unit configured to convey the rebar tying unit; and a control unit configured to control an operation of the conveying unit, wherein the conveying unit comprises: a longitudinal movement mechanism configured to move the rebar tying robot in a front-rear direction; and a first three-dimensional distance sensor configured to output first point cloud data which represents a three-dimensional position of an object in a first field of view by point clouds, and the control unit is configured to execute: a first rebar extraction process in which the control unit extracts, from the point clouds included in the first point cloud data, point clouds whose positions in an up-down direction are within a predetermined rebar depth range; and a rebar model generation process in which the control unit generates a rebar model in which the primary rebar or the secondary rebar is modeled by a linear line based on the point clouds extracted in the first rebar extraction process.

2. The rebar tying robot according to claim 1, wherein the control unit is configured to execute a cluster extraction process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds included in a largest cluster, and the rebar model generation process is based on the point clouds extracted in the cluster extraction process.

3. The rebar tying robot according to claim 1, wherein the rebar model generation process includes: a secondary rebar model generation process in which the control unit generates a secondary rebar model in which the secondary rebar is modeled based on the point clouds extracted in the first rebar extraction process; a secondary rebar exclusion process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds that are not included in an area at or in a vicinity of the secondary rebar model; and a primary rebar model generation process in which the control unit generates a primary rebar model in which the primary rebar is modeled based on the point clouds extracted in the secondary rebar exclusion process.

4. The rebar tying robot according to claim 3, wherein the rebar model generation process further includes a secondary rebar extraction process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds that are within a secondary rebar candidate area, the secondary rebar candidate area being defined based on positions of point clouds located at or in a vicinity of opposite ends in the left-right direction, and the secondary rebar model generation process is based on the point clouds extracted in the secondary rebar extraction process.

5. The rebar tying robot according to claim 4, wherein in the secondary rebar model generation process, the secondary rebar model is generated according to a RANSAC method.

6. The rebar tying robot according to claim 1, wherein the first three-dimensional distance sensor is directed downward.

7. The rebar tying robot according to claim 1, wherein the conveying unit further comprises a second three-dimensional distance sensor configured to output second point cloud data which represents a three-dimensional position of an object in a second field of view by point clouds, the second field of view being rearward of the first field of view, the control unit is configured to further execute a second rebar extraction process in which the control unit extracts, from the point clouds included in the second point cloud data, point clouds whose positions in an up-down direction are within the rebar depth range, and the rebar model generation process is also based on the point clouds extracted in the second rebar extraction process.

8. The rebar tying robot according to claim 7, wherein the rebar model generation process includes: a first secondary rebar model generation process in which the control unit generates a secondary rebar model in which the secondary rebar is modeled based on the point clouds extracted in the first rebar extraction process; a first secondary rebar exclusion process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds that are not included in an area at or in a vicinity of the secondary rebar model generated in the first secondary rebar model generation process; a second secondary rebar model generation process in which the control unit generates a secondary rebar model in which the secondary rebar is modeled

based on the point clouds extracted in the second rebar extraction process; a second secondary rebar exclusion process in which the control unit further extracts, from the point clouds extracted in the second rebar extraction process, point clouds that are not included in the area at or in the vicinity of the secondary rebar model generated in the second secondary rebar model generation process; and a primary rebar model generation process in which the control unit generates a primary rebar model in which the primary rebar is modeled based on the point clouds extracted in the first secondary rebar exclusion process and the point clouds extracted in the second secondary rebar exclusion process.

9. The rebar tying robot according to claim 8, wherein in the primary rebar model generation process, the primary rebar model is generated according to a least square method.

10. The rebar tying robot according to claim 7, wherein the first three-dimensional distance sensor and the second three-dimensional distance sensor are directed downward.

11. The rebar tying robot according to claim 1, wherein the conveying unit comprises a crawler configured to move on the plurality of primary rebars and the plurality of secondary rebars.

12. The rebar tying robot according to claim 2, wherein the rebar model generation process includes: a secondary rebar model generation process in which the control unit generates a secondary rebar model in which the secondary rebar is modeled based on the point clouds extracted in the first rebar extraction process; a secondary rebar exclusion process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds that are not included in an area at or in a vicinity of the secondary rebar model; and a primary rebar model generation process in which the control unit generates a primary rebar model in which the primary rebar is modeled based on the point clouds extracted in the secondary rebar exclusion process, the rebar model generation process further includes a secondary rebar extraction process in which the control unit further extracts, from the point clouds extracted in the first rebar extraction process, point clouds that are within a secondary rebar candidate area, the secondary rebar candidate area being defined based on positions of point clouds located at or in a vicinity of opposite ends in the left-right direction, the secondary rebar model generation process is based on the point clouds extracted in the secondary rebar extraction process, in the secondary rebar model generation process, the secondary rebar model is generated according to a RANSAC method, the first three-dimensional distance sensor is directed downward, and the conveying unit comprises a crawler configured to move on the plurality of primary rebars and the plurality of secondary rebars.

13. The rebar tying robot according to claim 9, wherein the first three-dimensional distance sensor and the second three-dimensional distance sensor are directed downward, and the conveying unit comprises a crawler configured to move on the plurality of primary rebars and the plurality of secondary rebars.