and warp caused by the movement of the passenger boarding bridge, and for this reason, accurate calculation cannot be performed. Therefore, it is considered that moving the head part (the cab) to a target position with high precision is difficult.

[0009] In the configuration of Patent Literature 3, the first and second cameras are installed at the terminal building, which is far away from the aircraft. For this reason, the relative position and relative angle of the head part with respect to the entrance of the aircraft cannot be calculated accurately. Therefore, it is considered that moving the head part (the cab) to a target position with high precision is difficult.

[0010] Embodiments of the present invention provide a passenger boarding bridge that makes it possible to move the cab to a target position with high precision.

Solution to Problem

[0011] According to an aspect of the present invention, there is provided a passenger boarding bridge including: a rotunda connected to a terminal building and rotatable in regular and reverse directions about a vertical axis; a tunnel unit whose proximal end is connected to the rotunda in such a manner that the tunnel unit is liftable and lowerable, the tunnel unit being configured to be extendable and retractable in a longitudinal direction of the tunnel unit; a cab rotatably provided at a distal end of the tunnel unit, a distal end part of the cab being to be docked with an entrance of an aircraft; a lifting/lowering device mounted to the tunnel unit or the cab and configured to lift and lower the tunnel unit or the cab by extending and retracting in a longitudinal direction of the lifting/lowering device; a travel device mounted under the lifting/lowering device, the travel device being configured to travel on a ground and rotate in regular and reverse directions about an axis that passes through a center point of the travel device, such that a travel direction of the travel device is changeable; a cab rotator configured to rotate the cab; first and second cameras mounted to the cab and each configured to capture an image of the entrance of the aircraft; and a controller configured to control the travel device, the lifting/lowering device, and the cab rotator. The controller is configured to express a position of each part of the aircraft and of the passenger boarding bridge as position coordinates by using a three-dimensional orthogonal coordinate system in which a predetermined position is set as an origin. The controller is configured to perform: a first entrance position calculation process of causing the first and second cameras to capture images of the entrance, respectively, when the cab is at a predetermined standby position from which the cab is to start moving, and calculating position coordinates of a reference point on the entrance of the aircraft based on the images of the entrance captured by the first and second cameras, respectively; a cab stop position calculation process of, based on the position coordinates of the reference point on the entrance

calculated in the first entrance position calculation process, calculating target position coordinates of a reference point on the distal end part of the cab at a temporary stop position of the cab, the temporary stop position being such a position that when the cab is at the temporary stop position, the distal end part of the cab is located forward away from the entrance by a predetermined distance; a first inverse kinematics calculation process of, based on the target position coordinates of the reference point of the cab at the temporary stop position, the target position coordinates being calculated in the cab stop position calculation process, and a first desired rotational angle of the cab at the temporary stop position with respect to a particular horizontal direction, performing an inverse kinematics calculation to calculate target position coordinates of the center point of the travel device, a target length of the lifting/lowering device, and a target rotational angle of the cab with respect to the tunnel unit for the cab to be at the temporary stop position; and a first moving process of moving the cab from the standby position to the temporary stop position by performing: a process of causing the travel device to travel such that coordinates of the center point of the travel device are brought into coincidence with the target position coordinates calculated in the first inverse kinematics calculation process; a process of causing the lifting/lowering device to extend or retract to adjust a length of the lifting/lowering device to the target length calculated in the first inverse kinematics calculation process; and a process of driving the cab rotator to adjust a rotational angle of the cab with respect to the tunnel unit to the target rotational angle calculated in the first inverse kinematics calculation process.

[0012] According to the above aspect, the position of each part of the aircraft and of the passenger boarding bridge is expressed by position coordinates in the three-dimensional orthogonal coordinate system. When the cab is at the standby position, the position coordinates of the reference point on the entrance of the aircraft are calculated based on the images of the entrance captured by the respective first and second cameras, and based on the calculated position coordinates, the target position coordinates of the reference point on the distal end part of the cab at the temporary stop position are calculated. Then, based on the target position coordinates of the reference point of the cab and the orientation (the first desired rotational angle) of the cab at the temporary stop position, the inverse kinematics calculation is performed to calculate the target position coordinates of the center point of the travel device, the target length of the lifting/lowering device, and the target rotational angle of the cab with respect to the tunnel unit for the cab to be at the temporary stop position, and based on these calculation results, the travel device, the lifting/lowering device, and the cab rotator are driven to move the cab from the standby position to the temporary stop position.

[0013] As described above, when the cab is at the standby position, images of the entrance

of the aircraft are captured by the respective first and second cameras mounted to the cab, and the position of the reference point on the entrance is calculated as absolute coordinates (position coordinates in the three-dimensional orthogonal coordinate system). Based on the calculated absolute coordinates, the target position coordinates of the reference point of the cab at the temporary stop position are calculated. Accordingly, while the cab is moving from the standby position to the temporary stop position, since it is not necessary to calculate the position of the reference point on the entrance of the aircraft, it is also not necessary to perform image capturing by the first and second cameras, and moving the cab to the target position (the temporary stop position) can be performed with high precision.

[0014] In an embodiment of the above aspect, the first inverse kinematics calculation process may include: a first calculation process of, on an assumption that the cab is in a horizontal state, approximately calculating coordinates, in two respective horizontal directions, of a center point of the cab at the temporary stop position and the target rotational angle, of the cab with respect to the tunnel unit, corresponding to the first desired rotational angle by using the target position coordinates of the reference point of the cab at the temporary stop position and the first desired rotational angle of the cab at the temporary stop position with respect to the particular horizontal direction, then, on the assumption that the cab is in the horizontal state, calculating coordinates, in the two respective horizontal directions, of a foot of a perpendicular drawn onto a center line of the tunnel unit from the reference point of the cab at the temporary stop position, and by determining a coordinate of the foot of the perpendicular in a height direction to be the same as a coordinate of the reference point of the cab at the temporary stop position in the height direction, calculating position coordinates of the foot of the perpendicular; and a second calculation process of calculating the target position coordinates of the center point of the travel device and the target length of the lifting/lowering device for the cab to be at the temporary stop position by performing an inverse kinematics calculation by using the position coordinates, calculated in the first calculation process, of the foot of the perpendicular.

[0015] In an embodiment of the above aspect, the first desired rotational angle may be, in a plan view, an angle that is formed by the particular horizontal direction and a horizontal direction orthogonal to a fuselage guide line drawn on an apron.

[0016] In an embodiment of the above aspect, the passenger boarding bridge may further include a pair of distance sensors that are mounted to the cab such that the distance sensors are away from each other in a horizontal direction, the pair of distance sensors being configured to measure distances, respectively, each between the distal end part of the cab and the aircraft. The controller may be configured to further perform: a cab rotation process of, while the cab is stopped at the temporary stop position, driving the cab rotator to rotate the cab such that the

distances, each between the distal end part of the cab and the aircraft, measured by the pair of distance sensors, respectively, are equalized; a second entrance position calculation process of, after the cab rotation process, causing one of the first and second cameras to capture an image of the entrance, and calculating the position coordinates of the reference point on the entrance based on the captured image of the entrance and the distances, each between the distal end part of the cab and the aircraft, measured by the pair of distance sensors, respectively; a cab docking position calculation process of calculating target position coordinates of the reference point of the cab at a docking position of the cab, the docking position being a position at which the distal end part of the cab is to be docked with the entrance, based on the position coordinates, calculated in the second entrance position calculation process, of the reference point on the entrance; a second inverse kinematics calculation process of calculating target position coordinates of the center point of the travel device, a target length of the lifting/lowering device, and a target rotational angle of the cab with respect to the tunnel unit for the cab to be at the docking position by performing an inverse kinematics calculation based on the target position coordinates, calculated in the cab docking position calculation process, of the reference point of the cab at the docking position and a second desired rotational angle of the cab at the docking position with respect to the particular horizontal direction; and a second moving process of moving the cab from the temporary stop position to the docking position by performing: a process of causing the travel device to travel such that the center point of the travel device moves toward the target position coordinates calculated in the second inverse kinematics calculation process; a process of extending or retracting the lifting/lowering device to adjust the length of the lifting/lowering device to the target length calculated in the second inverse kinematics calculation process; and a process of driving the cab rotator to adjust the rotational angle of the cab with respect to the tunnel unit to the target rotational angle calculated in the second inverse kinematics calculation process.

[0017] According to the above embodiment, when the cab is at the temporary stop position, the cab is rotated such that distances each between the distal end part of the cab and the aircraft are equalized. Then, based on an image of the entrance captured by one of the first and second cameras and the distances each between the distal end part of the cab and the aircraft, the distances being measured by the respective distance sensors, the position coordinates of the reference point on the entrance of the aircraft are calculated, and based on the calculated position coordinates, the target position coordinates of the reference point on the distal end part of the cab at the docking position are calculated. Then, based on the target position coordinates of the reference point of the cab and the orientation (the second desired rotational angle) of the cab at the docking position, the inverse kinematics calculation is performed to calculate the target

position coordinates of the center point of the travel device, the target length of the lifting/lowering device, and the target rotational angle of the cab with respect to the tunnel unit for the cab to be at the docking position, and based on these calculation results, the travel device, the lifting/lowering device, and the cab rotator are driven to move the cab from the temporary stop position to the docking position.

[0018] As described above, when the cab is at the temporary stop position, the position of the reference point on the entrance of the aircraft is calculated as absolute coordinates, and based on the absolute coordinates, the target position coordinates of the reference point of the cab at the docking position are calculated. Accordingly, while the cab is moving from the temporary stop position to the docking position, since it is not necessary to calculate the position of the reference point on the entrance of the aircraft, it is also not necessary to perform image capturing by the cameras, and moving the cab to the target position (the docking position) can be performed with high precision. Also, at the temporary stop position, distances each between the distal end part of the cab and the aircraft are measured by the respective distance sensors. Accordingly, the position coordinates of the reference point on the entrance can be calculated with high precision, and also, the docking position of the cab can be calculated with high precision. Consequently, automatic docking of the cab with the aircraft can be performed properly.

[0019] In an embodiment of the above aspect, the second inverse kinematics calculation process may include: a third calculation process of, on an assumption that the cab is in a horizontal state, approximately calculating coordinates, in two respective horizontal directions, of a center point of the cab at the docking position and the target rotational angle, of the cab with respect to the tunnel unit, corresponding to the second desired rotational angle by using the target position coordinates of the reference point of the cab at the docking position and the second desired rotational angle of the cab at the docking position with respect to the particular horizontal direction, then, on the assumption that the cab is in the horizontal state, calculating coordinates, in the two respective horizontal directions, of a foot of a perpendicular drawn onto a center line of the tunnel unit from the reference point of the cab at the docking position, and by determining a coordinate of the foot of the perpendicular in a height direction to be the same as a coordinate of the reference point of the cab at the docking position in the height direction, calculating position coordinates of the foot of the perpendicular; and a fourth calculation process of calculating the target position coordinates of the center point of the travel device and the target length of the lifting/lowering device for the cab to be at the docking position by performing an inverse kinematics calculation by using the position coordinates, calculated in the third calculation process, of the foot of the perpendicular.

[0020] In an embodiment of the above aspect, the second desired rotational angle may be, in

a plan view, an angle that is formed by the particular horizontal direction and a horizontal direction orthogonal to a tangent line that touches a part, of the aircraft, with which the cab is to be docked, the tangent line extending horizontally.

Advantageous Effects of Invention

[0021] Embodiments of the present invention as described above have an advantage of being able to provide a passenger boarding bridge that makes it possible to move the cab to a target position with high precision.

[0022] The above and other aspects, features, and advantages of the present invention will more fully be apparent from the following detailed description of preferred embodiments with accompanying drawings.

Brief Description of Drawings

[0023] FIG. 1 is a schematic plan view showing one example of a passenger boarding bridge according to an embodiment of the present invention.

FIG. 2 is a schematic side view of the passenger boarding bridge.

FIG. 3 is a side view showing one example of a state where a cab is docked with an aircraft.

FIG. 4 is a front view of a cab distal end part to be docked with the aircraft (the front view is taken from the aircraft side).

FIG. 5 shows one example of a control panel, etc.

FIG. 6 is a flowchart showing one example of operations of the passenger boarding bridge at the time of docking.

FIG. 7 is a schematic diagram showing one example of an image captured by a camera when the cab is at a standby position.

FIG. 8A is a diagram for describing one example of a target position of a reference point of the cab at a temporary stop position in relation to a reference point on an entrance of the aircraft, and FIG. 8B is a diagram for describing one example of a target position of the reference point of the cab at a docking position in relation to the reference point on the entrance of the aircraft.