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Development of Walking Support System Based on Dynamic Simulation

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***Abstract*— The humanoid bipedal robot WABIAN-2R was developed to be used as human motion simulator. It is able to perform similar human-like walking motion. Moreover, the robot is able to perform walking motions with a walking support device. This walking device was moving passively helping the robot to move easily. However, to go further with this development, we have to test the robot using the walking device with different conditions such as activating its wheel motors. Conducting this experiment is expected to be highly risky and costly. Therefore, we had developed a dynamic simulator in order to test the performance of the robot using the walking support device before conducting it in real simulation.**

Index Terms - Dynamic Simulation, Humanoid Robot, Biped robot, Walking Support Device.

I. Introduction

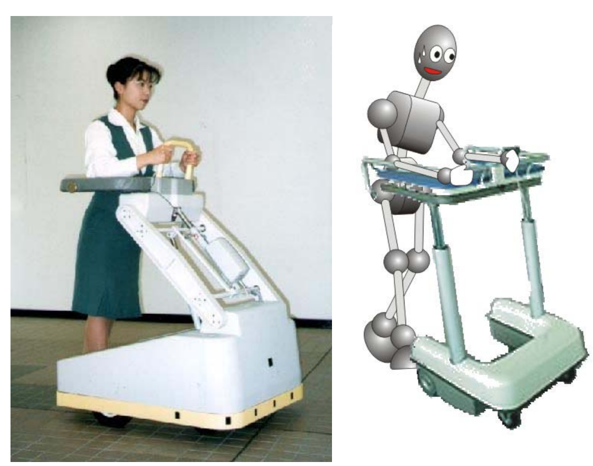
With the rapid aging of society in recent times, the number of people with limb disabilities is increasing. According to the research by the Health, Labour and Welfare Ministry, Japan, there are around 1,749,000 people with limb disabilities; this accounts for more than half of the total number of disabled people (3,245,000 handicapped people)[1]. The majority of these people suffer from lower-limb disabilities. Therefore, the demands for establishing a human walking model that can be adapted to clinical medical treatment are increasing. Moreover, this model is required for facilitating the development of rehabilitation and medical welfare instruments such as walking machines for assistance or training (see Fig. 1(a)). However, experiments that are carried out to estimate the effectiveness of such machines by the elderly or handicapped could result in serious bodily injury.

Many research groups have been studying biped humanoid robots in order to realize the robots that can coexist with humans and perform a variety of tasks. For examples, a research group of HONDA has developed the humanoid robots—P2, P3, and ASIMO[2]. The Japanese National Institute of Advanced Industrial Science and Technology (AIST) and Kawada Industries, Inc. have developed HRP-2P. The University of Tokyo developed H6 and H7, and the Technical University of Munich developed Johnnie. Waseda University developed the WABIAN series that realized various walking motions by using moment compensation. Korea Advanced Institute of Science and Technology (KAIST) also developed a 41-DOF humanoid robot— KHR-2 [3].

The above mentioned human-size biped robots achieved dynamic walking. If these humanoid robots can use rehabilitation or welfare instruments as shown in Fig. 1(b), they will be able to help in testing such instruments quantitatively. The main advantages of the human simulator can be considered to be as follows: (1) The measurement of the angle and the torque required at each joint can be measured easily and quantitatively as compared to the corresponding values in the case of a human measurement. (2) Experiments using such robots can help identify leg defects of a human from an engineering point of view. (3) A robot can replace humans as experimental subjects in various dangerous situations: experiments involving the possibility of falling, tests with incomplete prototype instruments, simulations of paralytic walks with temporarily locked joints.

Such experiments require a humanoid robot that enables it to closely replicate a human. However, humans have more redundant DOFs than conventional biped humanoid robots; this feature enables them to achieve various motions. Therefore, a DOF configuration that is necessary to reproduce such motions is one of the very important issues in the development of a humanoid robot [4].

The Waseda Bipedal Humanoid Robot WABIAN-2R has been developed to simulate human motion. WABIAN-2R



(a) by human (b) by robot

Fig. 1. Walking support system

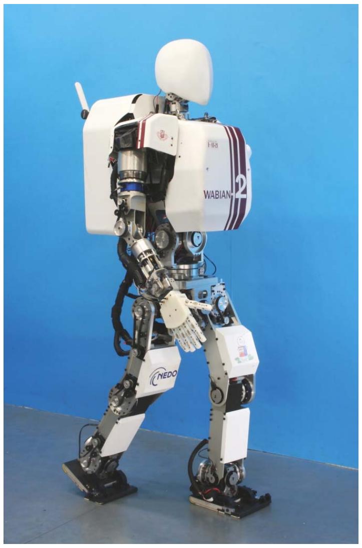


Fig.2.WABIAN-2R

performed human-like walking motions (see Fig. 2). Moreover, WABIAN-2R achieved to perform walking motion using walk-assist machine. However, the walk-assist machine was freely rolling without activating its wheels motors. In this case, the robot faced the minimum resistance or disturbance case by the walk-assist machine. On the other hand, activating the walk-assist machine may create a large disturbance for robot due to separate control for each of them. Conducting this experiment may be highly risky.

As we develop humanoid robot to coexist in the human environment, we need to conduct many experiments such as robot walking on uneven surface, climbing the stairs, and robot interact with other machine and instruments. Doing any new type of experiment using WABIAN-2 might be risky. Therefore, we need find a safer method for initial experimental testing. Using a dynamic simulation is useful method due to some reasons such as: (1) It is safer in terms of cost and risk. (2) It is easy to monitor and view motion outputs. (3) It can show the variation cased by any external disturbances. In this paper, a dynamic simulator is described, which is able to easily simulate any new type of walking. Using the dynamic simulator, we can monitor the motion performance and output all needed data that is useful for further development. This paper is aimed to simulate the walking motions of WABIAN-2 using walk-assist machine.

II. Dynamic Simulation

Dynamic simulation could be used to simulate the dynamic motion of a mechanical structured model. It can analyze the effects of the surrounding environment on the mechanisms and objects. In robotics researches, simulation software is used for robotic simulation. There are many simulator used for robotics simulation in different applications. Most of those simulators are for industrial robot applications. However, there are some simulators used for mobile robot simulation. Webots is one of the high and advanced simulation software used in Robotics simulation. It is use for prototyping and simulation of mobile robots. It has many advanced functions and techniques. Webots is very easy to use and implement. Therefore, we choose it as simulation software [5].

A. Modeling

In order to develop a dynamic simulation, we need to go through several steps. First is modeling where we set up the simulation environment and initial parameters. We set up a full structure of WABIAN-2, based on the specifications (size, shape, mass distribution, friction, .etc) of components of WABIAN-2 (see Fig. 3).

B. Controlling

Second is controlling, which identifies simulation objects and controls the simulation procedures. The controller is some how similar to the WABIAN-2R control. It gets the input data from the CSV pattern file, and sets the position angle of each joint through inverse kinematics techniques. Moreover, the controller sets the simulate time step and the measurement of data.

C. Running

Lastly is the running of the simulation and checking the dynamic motion. We can view the simulation from different view sides which gives us a clear idea about the simulation performance. Moreover, most of the needed data could be measured through several functions.

III. Walking with Walking Support Device

WABIAN-2 performed some walking experiments using walking assist machine. The performance was conducted by leaning its arms on the walking assist machine holder. The walking assist machine moves passively without generating its own motion (see Fig. 4). The robot was able to walk and push the walking assist machine forward. The experiments were conducted with different walking styles and different heights of arm rest.

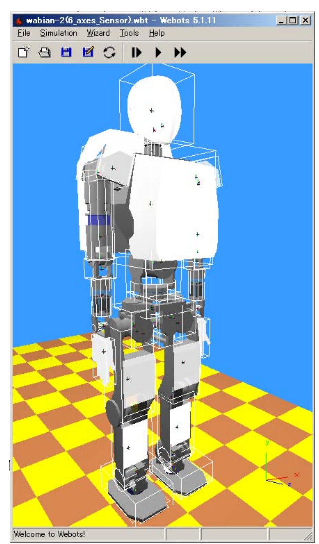


Fig. 3. Modeled WABIAN-2R in the simulation world

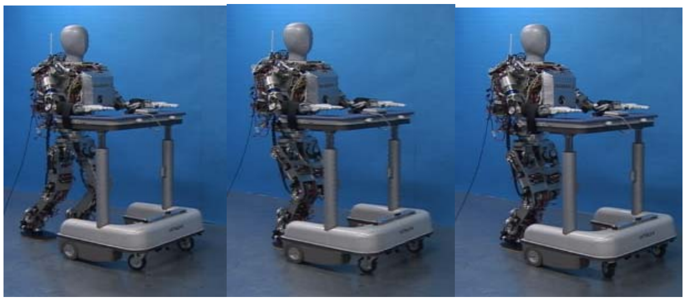


Fig. 4. WABIAN-2 using the Walking Support Device

The walking performance of WABIAN-2 using an active walking assist machine, expected to be unstable. The walk-assist machine has its own control system, not connected to WABIAN-2 control system. The walking assist machine moves with constant velocity in a forward direction, while the robot moves by setting its position. The robot arms may displace from its position on the arm rest of the machine which will case external forces on WABIAN-2. In order to stabilize the walking, the external force has to be minimized.

A. Force Sensor

The real walking assist machine is developed to sense the force applied by the load on the arm rest. A force sensor is attached on the top of the arm rest consisting of four displacement sensors. The displacement sensor is simply a spring mechanism. It senses forward and vertical forces and turns toque by determining relative displacements between the upper frame and the lower one (see Fig. 5). We can develop the system that can adjust the velocity of the walking assist machine in order to minimize the displacement.

Measuring forces acting between upper and lower frame are determine through the amount of displacement and orientation between them. Assuming that each frame has its own coordinate system, the displacements in each axis are set as D_x, D_y, and D_z and the orientation around Y axis and Z axis are set as D_{ry}, and D_{rz} (see Fig. 6) .

The forces are determined through the following equations:

$$\begin{aligned} F_y &= 4C_{sx}D_y \\ F_z &= 4C_{sz}D_z \\ F_{rz} &= \left(L_1^{\,2} + L_2^{\,2}\right)\cdot C_{sx}D_{rz} \end{aligned} \tag{1}$$

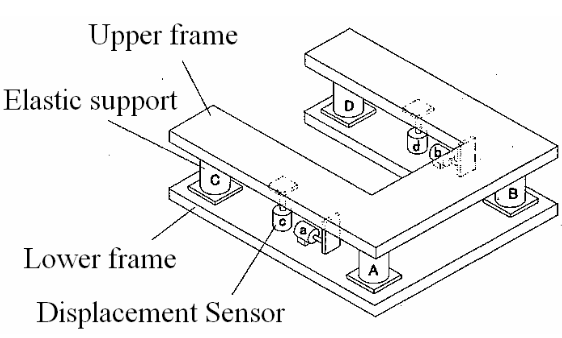


Fig. 5. Force Sensor

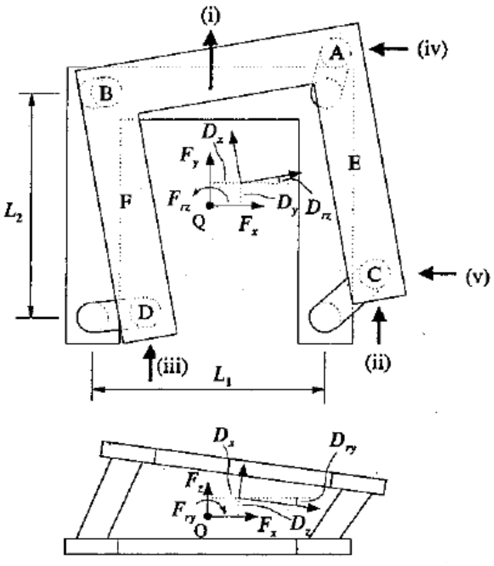


Fig. 6. Definition of Forces and Displacements

where C_{sx} and C_{sz} are the spring constant of the displacement sensors in horizontal and vertical directions. L_1 and L_2 are the distance between the elastic support in X and Y directions. The output of the displacement sensors a, b, c, and d are set as S_a, S_b, S_c, and S_d. The amounts of displacement are determined through the following equations:

$$\begin{aligned} S_a &= D_y + \left(L_1/2\right)D_{rz} \\ S_b &= D_y - \left(L_1/2\right)D_{rz} \\ S_c &= D_z - \left(L_1/2\right)D_{ry} \\ S_d &= D_z + \left(L_1/2\right)D_{ry} \end{aligned} \tag{2}$$

Obtaining the previous formulas in (1) and (2) we can define the forces measurement from the displacements as follow:

$$\begin{aligned} F_y &= 2C_{sx}\left(S_a + S_b\right) \\ F_z &= 2C_{sz}\left(S_c + S_d\right) \\ F_{rz} &= \left(L_1 + L_2^{\,2}/L_1\right)\cdot C_{sx}\left(S_a - S_b\right) \end{aligned} \tag{3}$$

The forces and torque can be determined from the displacement cased in all the sensors. The amount of the spring constant of the horizontal direction (C_{sx}) is 105 kN/m and for the vertical direction (C_{sz}) is 490 kN/m. The displacement between the upper and lower frame is limit to 500mm to the sides (Right and Left) and 355mm forward and backward.

B. Velocity Control

The walking support device control system was be developed to adjust its speed according to the force applied on the arm rest [7]. The arm rest is designed to measure the force and torques applied by the user of the machine. The controller uses those measure data as an input data to set the velocity of each motor of the machine. In our simulation model, the robot

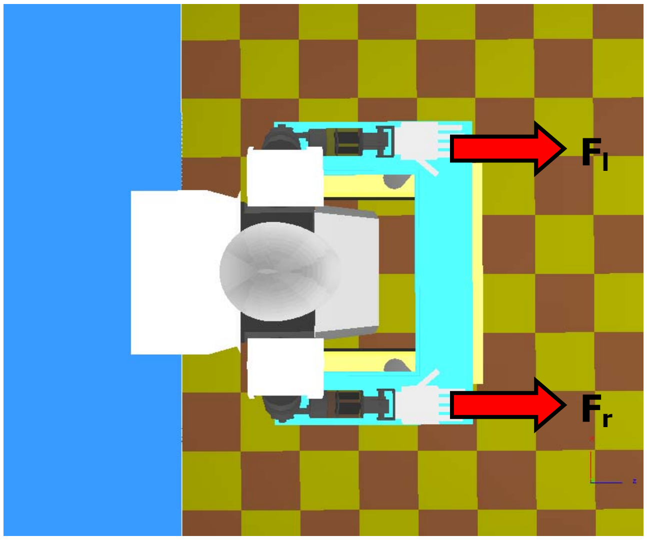


Fig. 7. Forces Applied by the Robot to the Arm Rest

applies forces by its arms on both sides of the arm rest (see Fig. 7). The sensor measures the amount of force by the displacement cased in each side of the arm rest.

We develop the controller for the walking device to adjust the velocity of each wheel according the force measure on the wheels side. Developing the equations of the modeled system, we can have the following equation:

$$F_y = m \cdot a \qquad (4)$$

where m is the total mass of the walking support device, a is the acceleration, and F_y is the force measured by the spring. The force is the result of displacement of the spring mechanism, which can be expressed as

$$F_y = C \cdot x \qquad (5)$$

where C is the spring constant and x is the amount of displacement. Substitute equation (5) in (4), we will have

$$a = C \cdot x \big/ m \qquad (6)$$

the acceleration is the derivative of velocity. Approximately, it is equal to the difference in velocity over step, which could be express as

$$a(t) = \left(v(t+\Delta t) - v(t)\right) \big/ \Delta t \qquad (7)$$

since we are dealing with discrete time, we can rearrange equation (7) to

$$a(k) = \left(v(k+1) - v(k)\right) \big/ T \qquad (8)$$

where v(k) is the current velocity, v(k+1) is the next velocity, and T is the step time. Substitute equation (6) in (8), we will have

$$v(k+1) = \left(C \cdot T \big/ m\right) \cdot x(k) + v(k) \qquad (9)$$

where x(k) refer to the displacement measured by the spring of the sensor. The constant value in equation (9) will be considered as the system gain. Therefore, equation (9) can be changed to

$$v(k+1) = G \cdot x(k) + v(k) \qquad (10)$$

where G is the control gain. The gain could be adjusted to check the response of the system according to the value set.

IV. Experiment

We had conducted many simulations to test the walking performance of the robot using the walking support device. In the simulator we can adjust the control gain of the walking device. The simulation result shows different response from the walking support device to the robot motion. We could not get a stable walking with G = 500 due to very low response by the machine controller (see Fig. 8). We could get a good walking performance with G = 10000. The robot had a little difficulty at the beginning of the walking but later it could walk easily with the device (see Fig. 8). When we set the gain to higher value we could get better walking motion and more stable as G = 25000 (see Fig. 10) and G = 40000 (see Fig. 11).

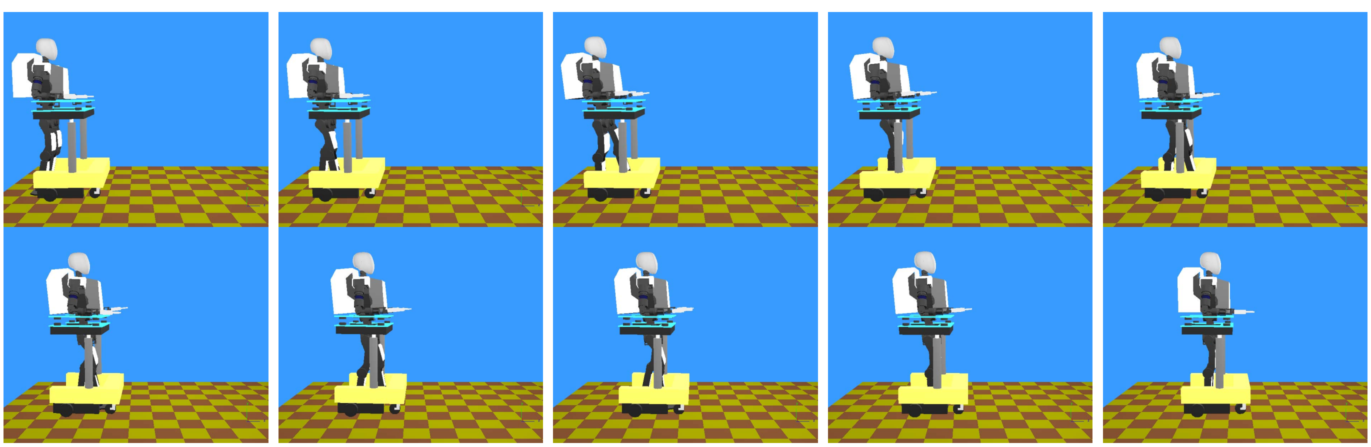


Fig. 8. Simulation of Walking with Walking Support Device with 500 Control Gain

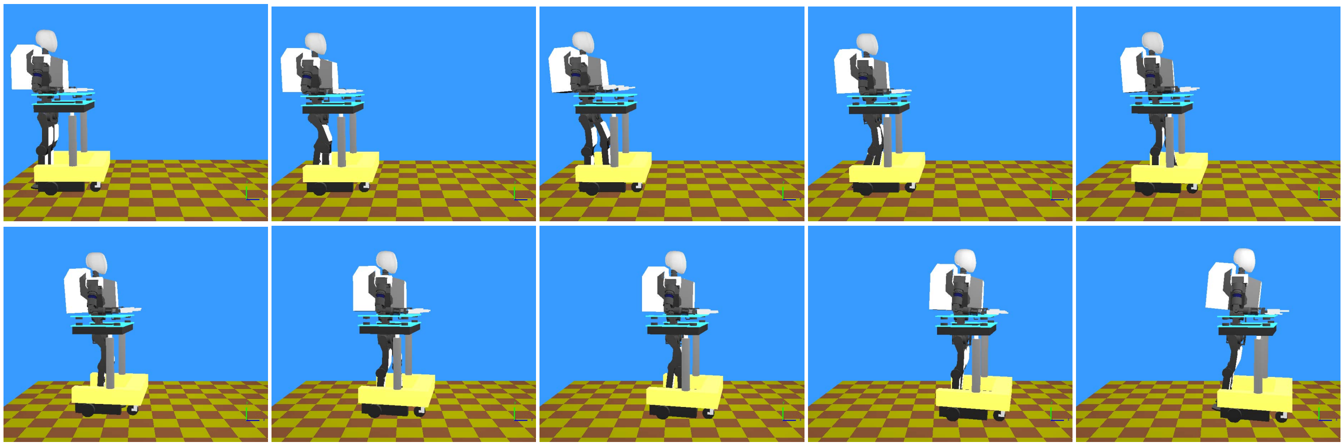


Fig. 9. Simulation of Walking with Walking Support Device with 10000 Control Gain

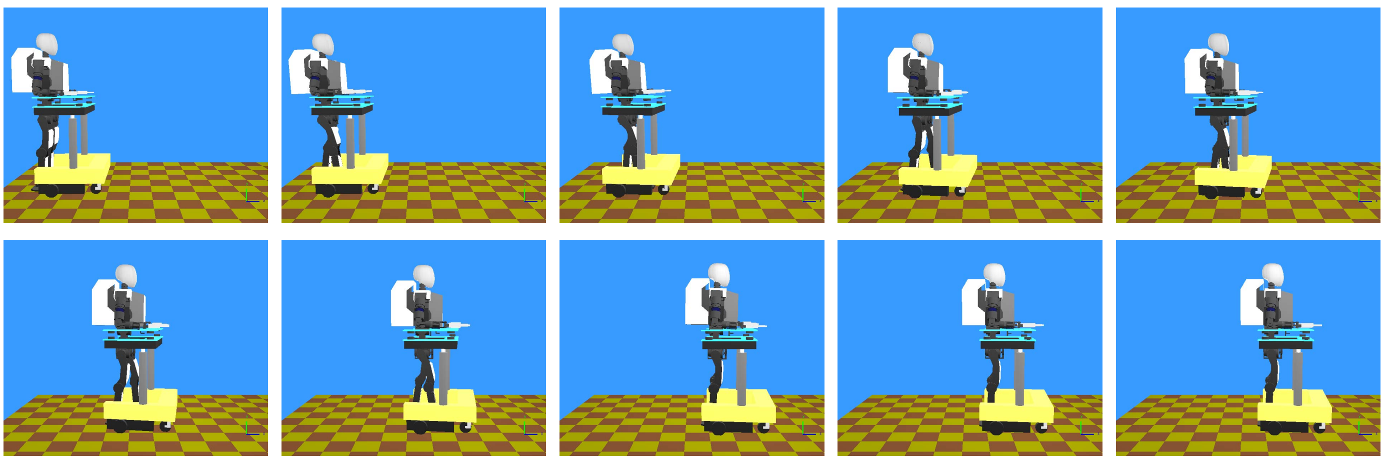


Fig. 10. Simulation of Walking with Walking Support Device with 25000 Control Gain

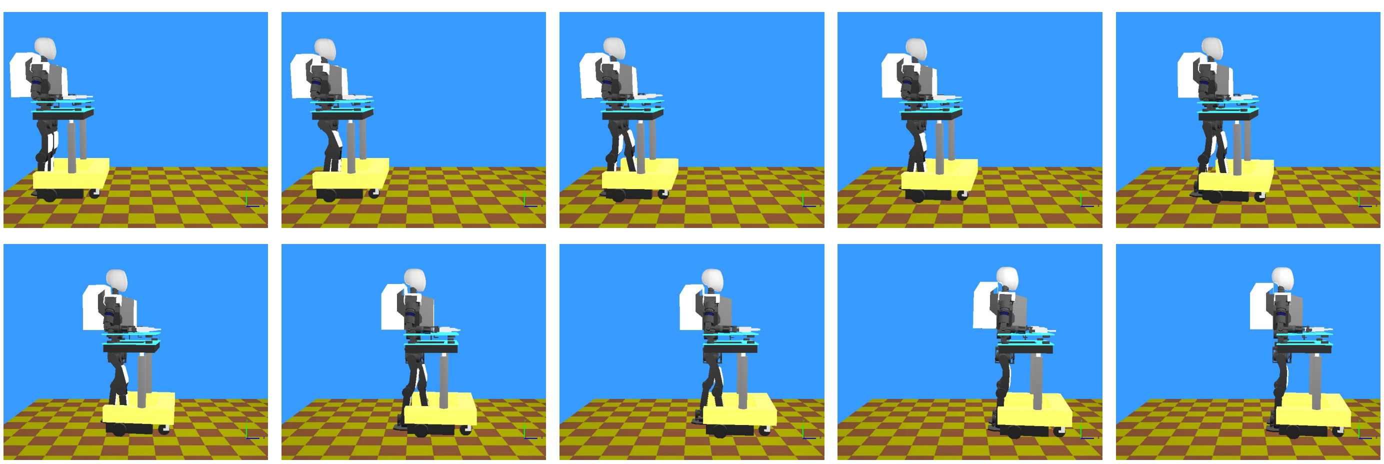


Fig. 11. Simulation of Walking with Walking Support Device with 40000 Control Gain

When we set the gain to a very low value the support device had a very low response to the force applied. The response that we could get when G = 500 is a very low velocity set to the wheels of the support device (see Fig. 12). The maximum velocity is 2 rad/s while in other simulation where the robot were able to walking the velocity of the walking support device went up to 40 rad/s (see Fig. 13).

V. Conclusion

This paper describes the simulation of a walking support system using WABIAN-2R. The dynamic simulation is very important to check the walking motion of robot. Using the dynamic simulation we can see the effect of the walking support device on WABIAN-2R. The controller in the walking device set the velocity in each wheel according to the force applied on the arm rest. The simulator can help us to check for the suitable gain for the walking device controller. A very low gain will result in a slow motion from the device while higher gain makes the device moves faster.

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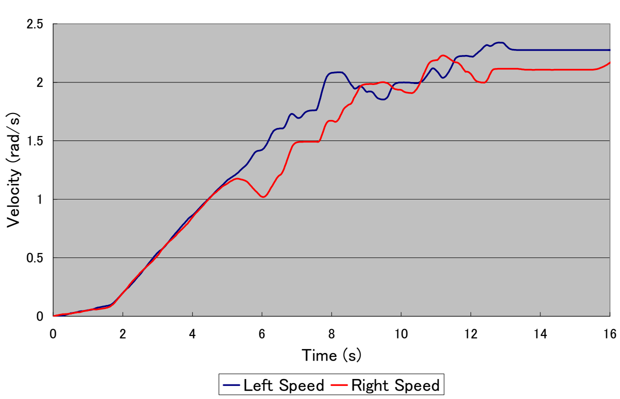
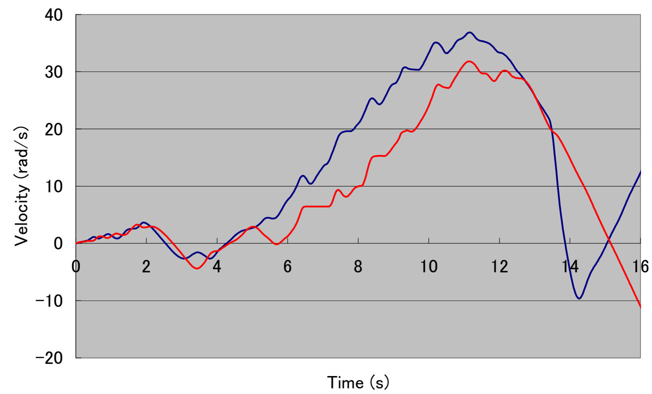
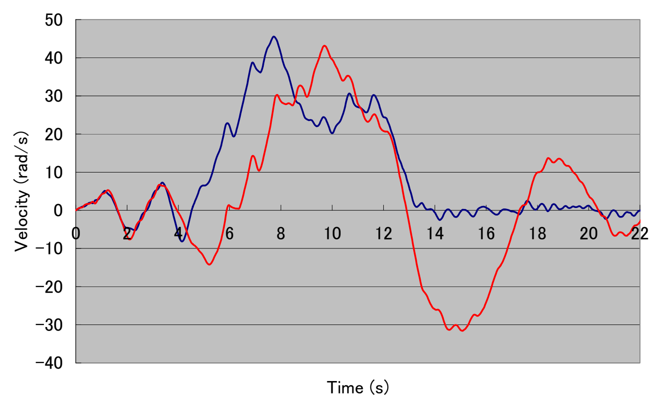


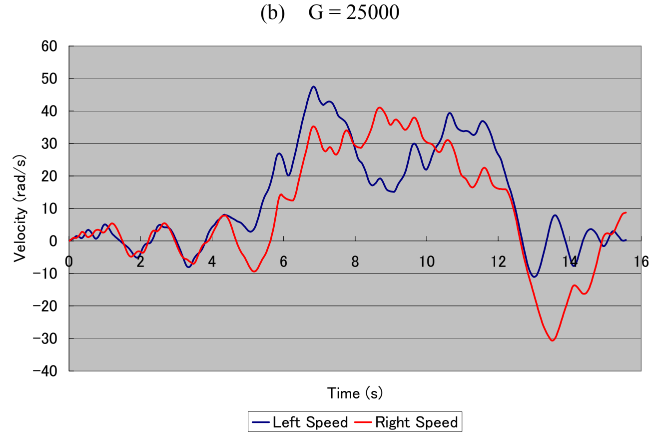
Fig. 12. Velocity set by the controller (G = 500)



(a) G = 10000



(b) G = 25000



(c) G = 40000

Fig. 13. Velocity set by the controller