Simulations for Elderly Support Walking Device with Humanoid Robot

Aiman Musa M. Omer, Hun-ok Lim, Atsuo Takanishi

***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.**

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). 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 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

(a) Walking assist machine (b) Walking training machine

Fig. 1. Rehabilitation instruments

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Fig.2.WABIAN-2R

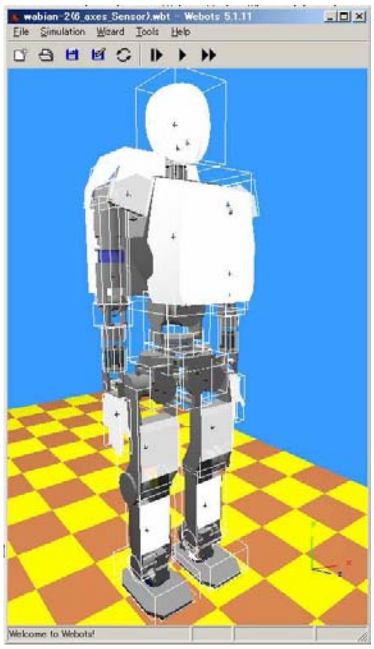

Fig. 3. Modeled WABIAN-2R in the simulation world

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 are used for robotic simulation. There are many software used for robotics simulation in different applications. Most of those software are for industrial robot applications. However, there are some software 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 (see Fig. 4).

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.

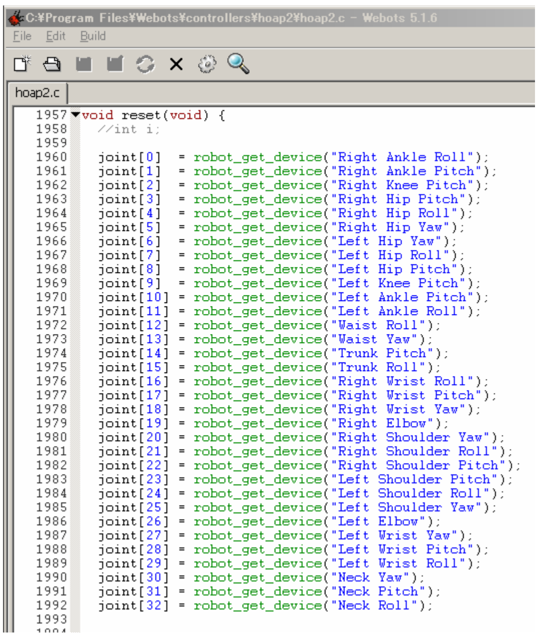

Fig. 4. Controller Reset Function

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 (see Fig. 5). The walking assist machine moves passively without generating its own motion. 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.

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. 6). 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. 7) .

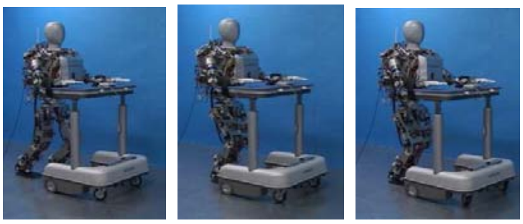

Fig. 5 Walking with a walking assist machine

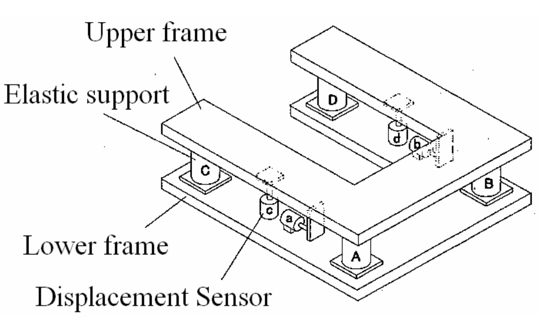

Fig. 6. Force Sensor

The forces are determined through the following equations:

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

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:

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

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

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

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.

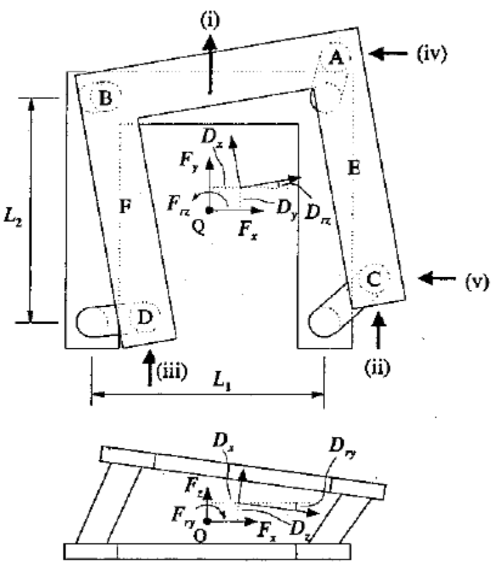

Fig. 7. Definition of Forces and Displacements

B. Velocity Control

There were some developments made on the walking assist machine control system 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 measured data as an input data to set the velocity of each motor of the machine.

In this study, we have introduced a new control system model that controls the velocity of the walking assist machine. The system adjusts the velocity according to the force measured by the force sensor. The new adjusted velocity is based on current velocity and the displacement with WABIAN-2.

Developing the equations of the modeled system, we can have the following equation:

$$F_y = m \cdot a \tag{4}$$

where *m* is the total mass of the walking assist machine, *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

$$F_y = C \cdot x \tag{5}$$

where C is the spring constant and x is the amount of displacement. Substitute equation (6) in (5), we will have

$$a = C \cdot x \big/ m \tag{6}$$

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

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

since we are dealing with discrete time, we can rearrange equation (8) to

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

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

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

where x(k) refer to the displacement measured by the spring of the sensor. This equation represents the velocity control process in the system.

IV. Experiment

We test several types of motions performed by WABIAN-2. The simulator simulates the walking performance of conventional walking and stretch walking. Moreover, it simulates some other motions as the input pattern. The dynamic simulation has given us a simulation motion just like the real simulation (see Fig. 8).

We conducted some simulation experiments of the robot walking using the walking device. The robot is able to walk stably with its knees bends and stretch just like the real experiment. The robot could walk and push the walking device which does not have any resistance torque in its wheels (see Fig. 9).

By adding the force sensor to the simulated walking assist machine, we were able to measure the amount of external force acting on the robot. We increase the resistance torque in the walking device wheels to check for the maximum torque that the robot can walk with the device. The robot was able to walk using walking device with 0.5 N.m as a maximum torque set (see Fig. 10).

We apply the velocity control to the walking device system and it helped the robot to walking using the walking device stably. With the help of the new controller the maximum torque get increased to 0.75 N.m instead of 0.5 N.m (see Fig. 11).

The force sensor attached on top of the walking device measured the horizontal and vertical force applied by the robot. The sensor could measure the force in each side (see Fig. 12 and Fig. 13).

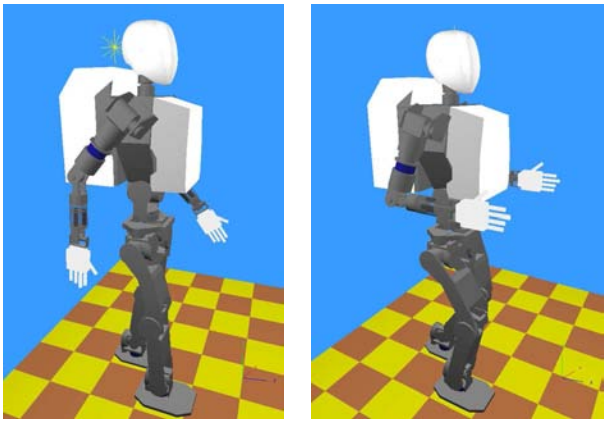

Fig. 8. Simulation of Different Type of Walking

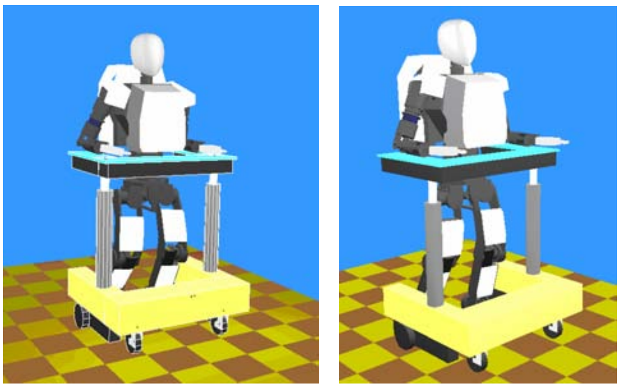

Fig. 9. Simulation of Walking Support System

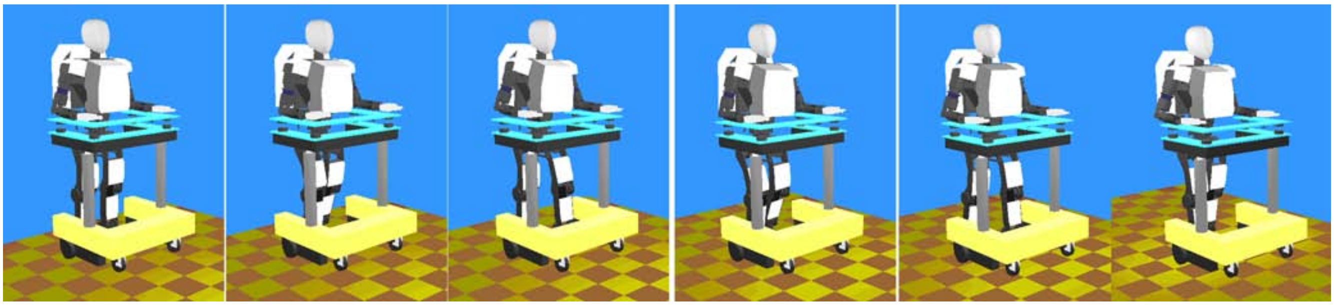

Fig. 10. Simulation of Walking with Walking Support System that have a Force Sensor

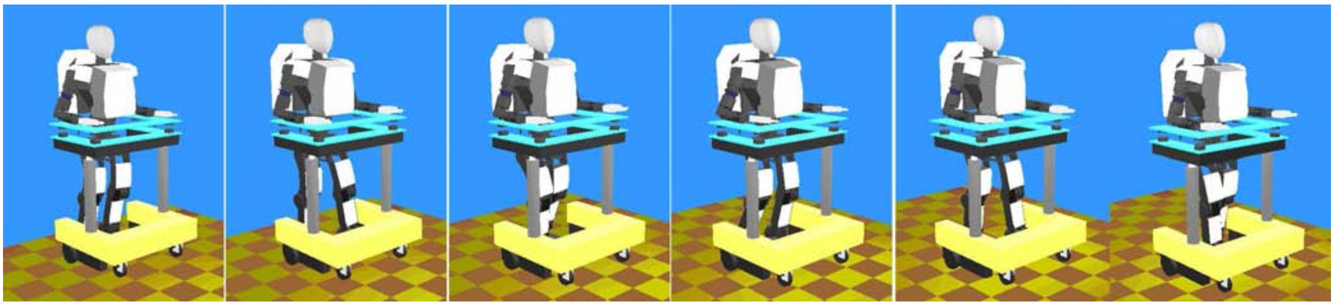

Fig. 11. Simulation of Walking with Walking Support System using the Velocity Control

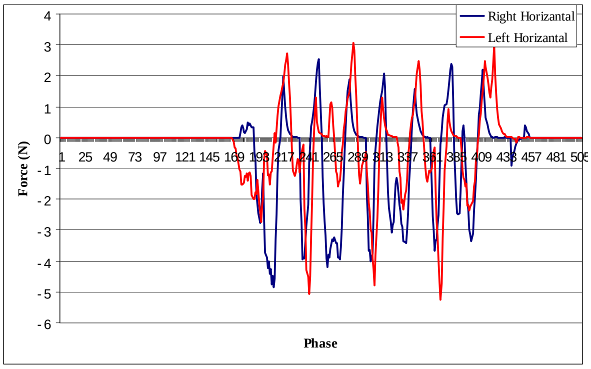

Fig. 12. Measurement of the Right (blue) and Left (Red) Horizontal Forces by the Force Sensor

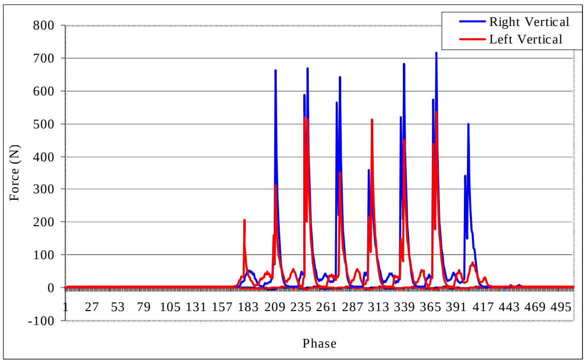

Fig. 13. Measurement of the Right (blue) and Left (Red)Vertical Forces by the Force Sensor

V. Conclusion

This paper describes the simulation of walking by WABIAN-2R with the walking assist machine. The dynamic simulation is very important to check the motion of any new pattern generated. Using the dynamic simulation we can see the effect of the walking assist on WABIAN-2R. These experiments and simulation are very important for a development of a walking support system for elderly people.

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