Dynamic-Based Simulation for Humanoid Robot Walking Using Walking Support System

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1. 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 (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.

(a) by human (b) by robot

Fig. 1. Walking support system

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 (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.

Fig. 2.WABIAN-2R

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: (a) It is safer in terms of cost and risk. (b) It is easy to monitor and view motion outputs. (c) 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.

2. Dynamic simulation

Dynamic simulation could be used the purpose of testing and checking the dynamic motion of a mechanical structured model. It has the advantages of saving cost and risk which are highly needed in a development of a mechanical structure. There are many simulation software have been developed for robotics application, mainly for the industrial robot applications. However, there are some software used for mobile robot simulation. For examples, RoboWorks, SD/FAST, OpenHRP, Webots, and Yobotics are used for mobile and legged robot simulation. Webots is 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 for our research [5].

2.1 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 (Fig. 3).

Fig. 3.WABIAN-2R Structure is been modeled in the Simulated World

2.2 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.

2.3 Running

The program in the controller section of the simulator will run by going through the main function. There are several steps the controller will go through. First, check the pattern file and prepare to read through the lines. Then read the data from one line. The data is in terms of position and orientation of foots and hands. Using these data we calculate each joint position through inverse kinematics techniques. After that it will set all positions to its joint. The controller runs one control step of 30ms which is similar to the real robot. The controller goes through all the lines in the pattern file until it is completed in the last line.

When the simulation runs it can be viewed the simulation from different view sides. This can gives us a clear idea about the simulation performance. Moreover, most of the needed data could be measured through several functions.

3. Walking with Walking Assist Machine

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. 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. 4).

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.

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

3.1 Force Sensor

The researches conducted on the walking assist machine are focusing on the relation between the machine and the human user. One of the latest studies promote the idea of measure the forces applied by the user on the machine arm rest. They develop a force sensor in terms of a displacement sensor (Fig. 5). The force sensor is constructed by connecting two flat plates with displacement sensors in between.

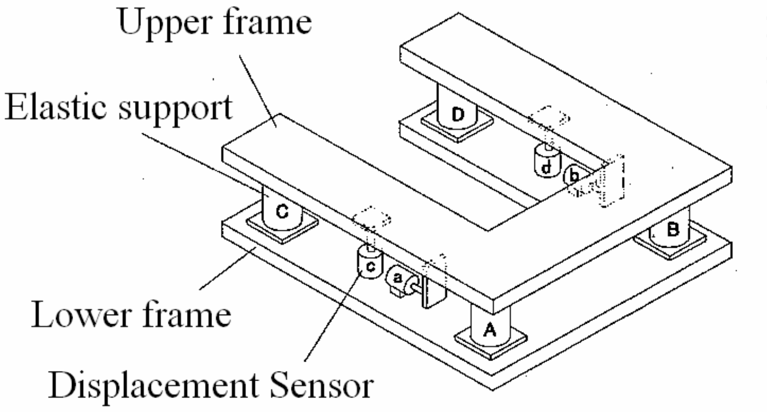


Fig. 5. Force Sensor

This force sensor is attached on top of the arm rest in the walking assist machine. It measures the forces by sensing the amount of displacement measured by the position sensors. The signals generated by the sensor are sent to the controller of the walking assist machine in order to set the velocity and direction of motion.

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} (Fig. 6).

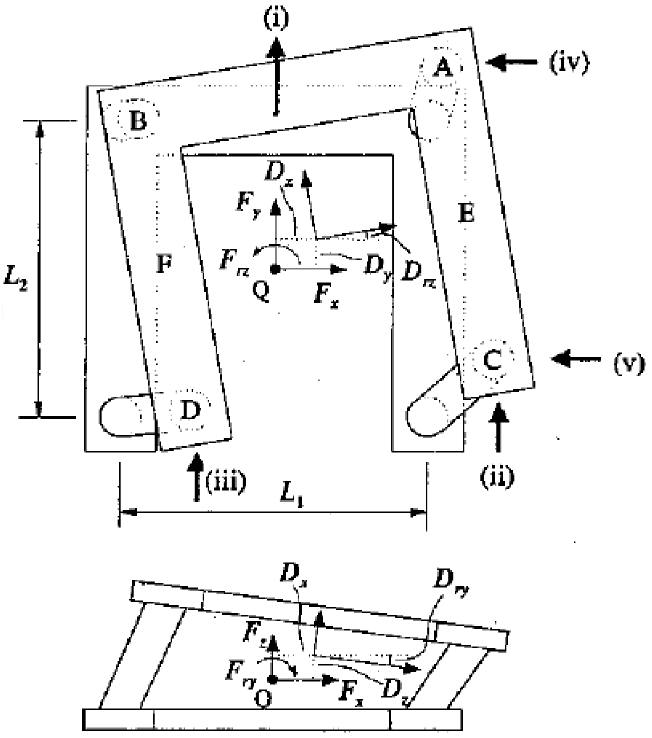


Fig. 6. Definition of Forces and Displacements

The forces are determined through the following equations:

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

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:

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

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

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

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.

3.2 Velocity Control

The walking assist machine control system is designed and developed to adjust its speed and direction 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 (Fig. 7). The force f_y and the turning moment m which applied by the arm of the user is calculated in the sensor by the following equations:

$$m_z = m + s_x f_y \tag{4}$$

where m_z is the moment measured by the sensor, s_x the distance shifted from the arm position to the sensor position. The values for m_z and f_y are the input data for the controller that set the velocity of each wheel motor (Fig. 7) [7].

In this study, we have developed the 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.

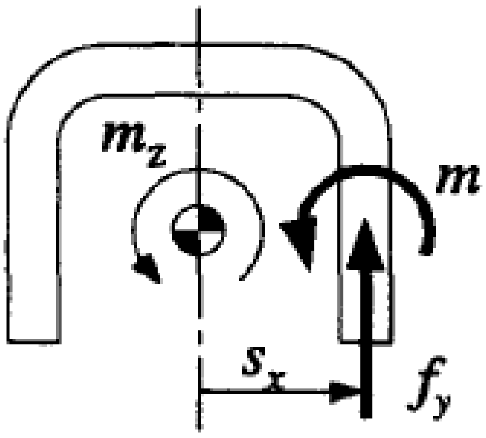


Fig. 7. Force and Moment Applied to Arm rest

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

$$F_y = ma \tag{5}$$

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

$$F_y = Cx \tag{6}$$

where C is the spring constant and x is the amount of displacement. Substitute equation (3) in (2), we will have

$$a = (C/m)\ x \tag{7}$$

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

$$a(t) = (v\ (t + \Delta t) - v\ (t))\ /\ \Delta t \tag{8}$$

since we are dealing with discrete time, we can rearrange equation (5) to

$$a(k) = (v(k+1) - v(k))\ /\ T \tag{9}$$

where v(k) is the current velocity, v(k+1) is the next velocity, and T is the step time. Substitute equation (4) in (6), we will have

$$v\,(k+1) = (C\,T\,/\,m)\;x(k) + v(k) \tag{10}$$

where x(k) refer to the displacement measured by the spring of the sensor. The constant value in equation (10) will be considered as the system gain. Therefore, equation (9) can be changed to

$$v\,(k+1) = G \cdot x(k) + v(k) \tag{11}$$

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

4. Simulation Result

Many simulations were conducted to test the walking performance of the robot using the walking support device. In the simulator the control gain of the walking device could be adjusted. The simulation result shows different response from the walking support device to the robot motion. Different control gain values of 1000, 2000, 5000, 7000, and 10000 were set to check the response of the system. Smaller gain value, like 1000 or 2000, result in slow response from the walking support device to the force applied by the robot on the arm rest. However, the robot faced some difficulties to walking with support device due to some differences in velocity between robot and the support device (see Fig. 8), or it can stop when the robot stop due to the slow response (see Fig. 9). On the other hand, when the gain was set to higher value, like 5000, 7000 or 10000, the response of the system get better by having much stable walking motion with the walking support device (see Fig. 10, Fig. 11 and Fig. 12).

The velocity set for each wheel is set according to the force applied by the robot arm on each side of the arm rest. If different amount of forces are applied in each side the velocity of each wheel is different which cases the walking support device make a turn. The device controller can set a high for velocity at the end of the robot walking due to sudden stop of the robot which cases a high force on the arm rest. This amount to high force stops to walking support device with the robot weight which is loaded on top of the arm rest (see Fig. 13, Fig. 14, Fig. 15, Fig. 16, and Fig. 17).

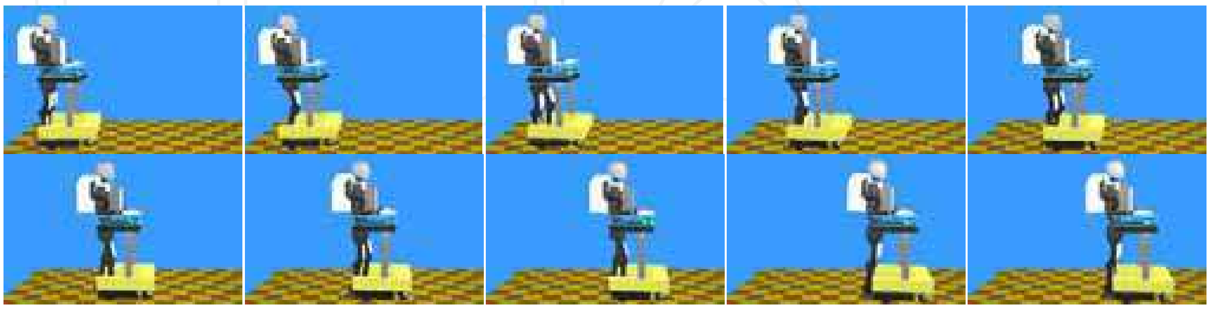


Fig. 8. Simulation of Walking with 1000 Gain

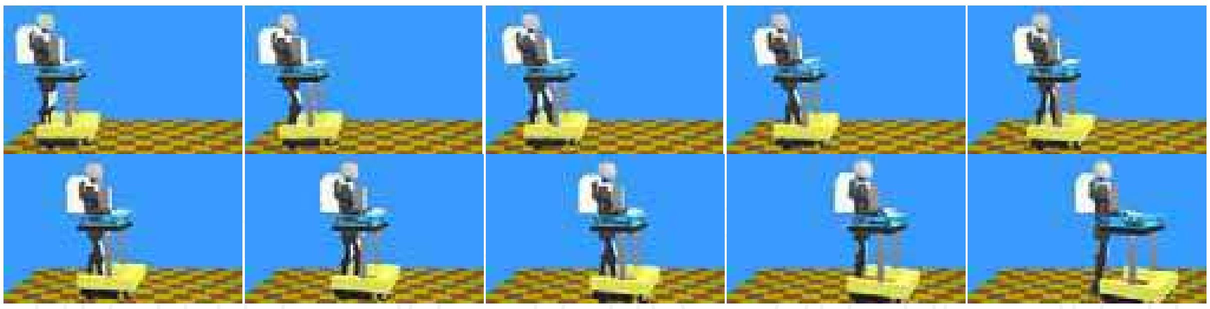


Fig. 9. Simulation of Walking with 2000 Gain

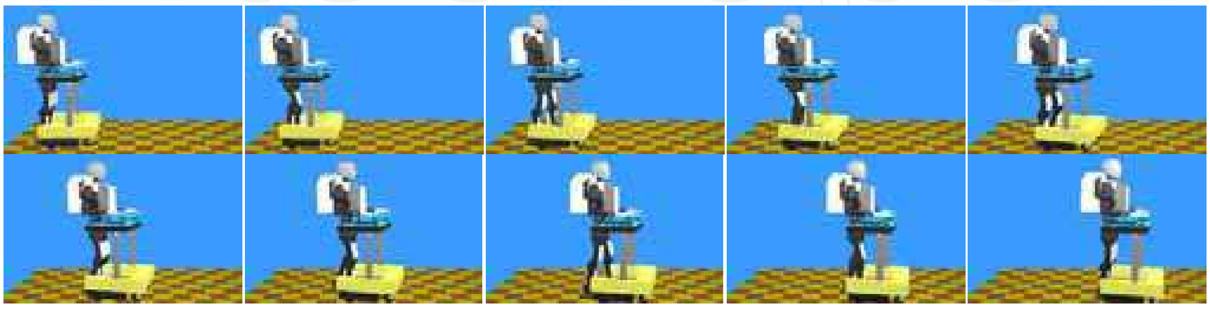


Fig. 10. Simulation of Walking with 5000 Gain

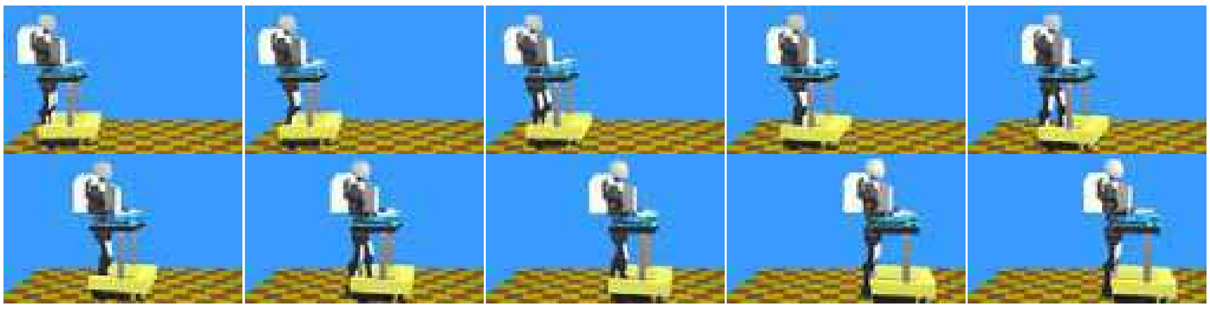


Fig. 11. Simulation of Walking with 7000 Gain

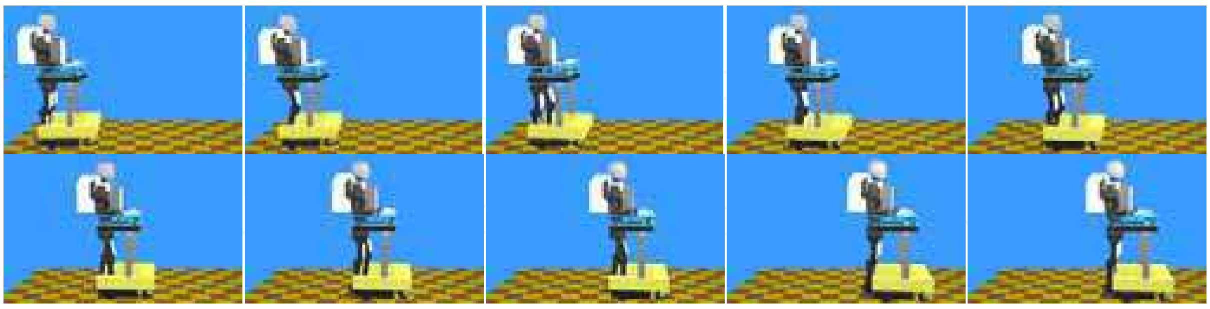
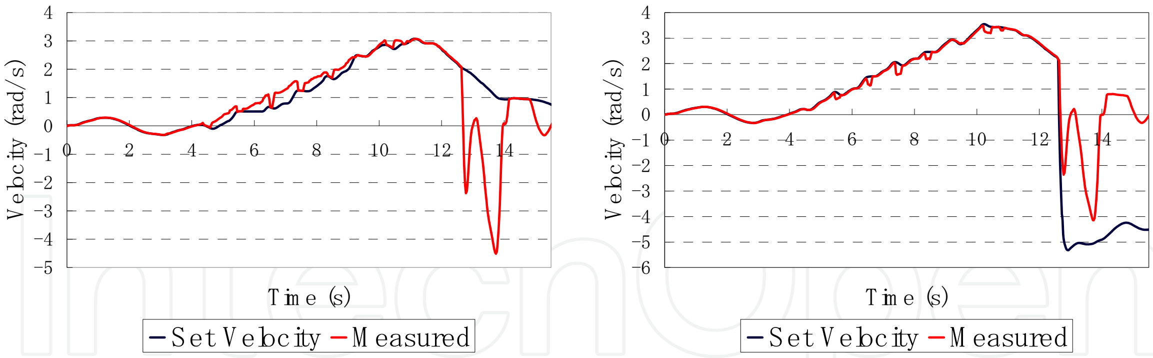
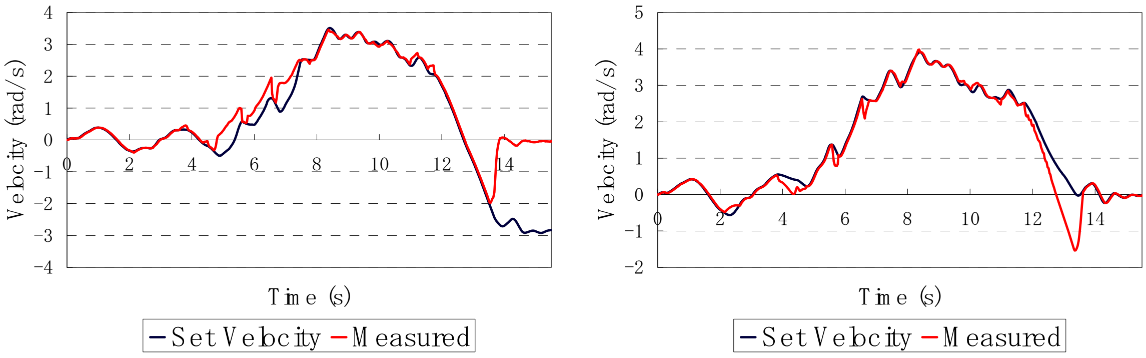


Fig. 12. Simulation of Walking with 10000 Gain



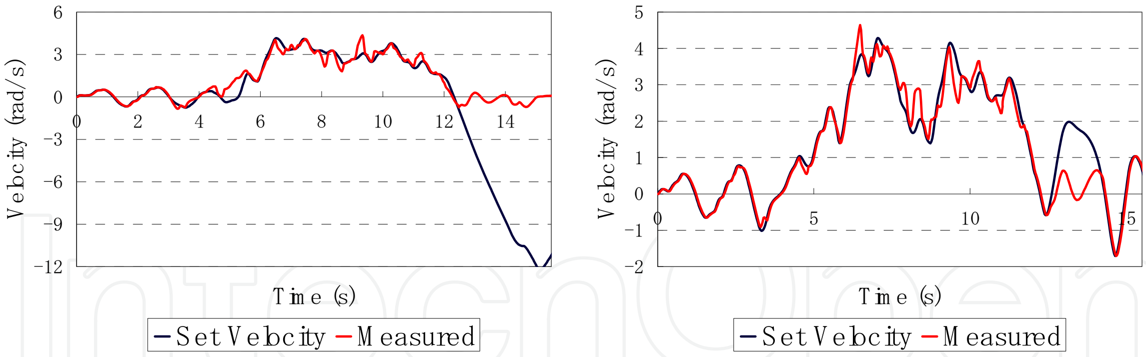
Left Wheel Right Wheel

Fig. 13. Velocity set and measured for each Wheel with 1000 Gain



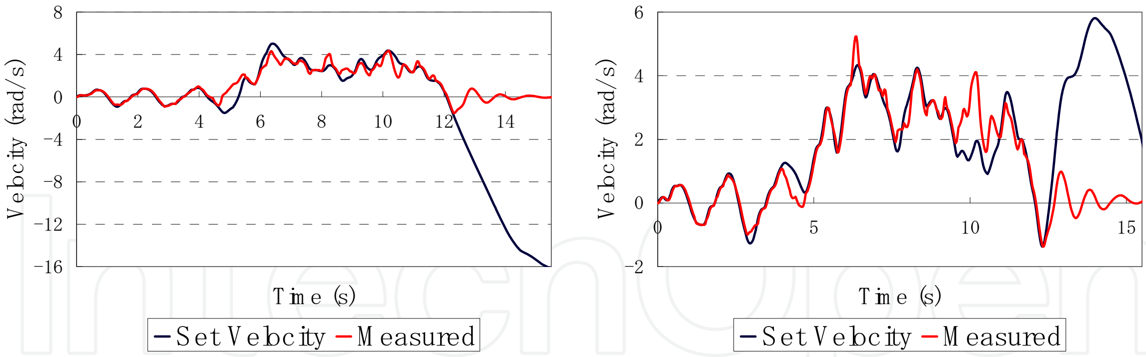
Left Wheel Right Wheel

Fig. 14. Velocity set and measured for each Wheel with 2000 Gain



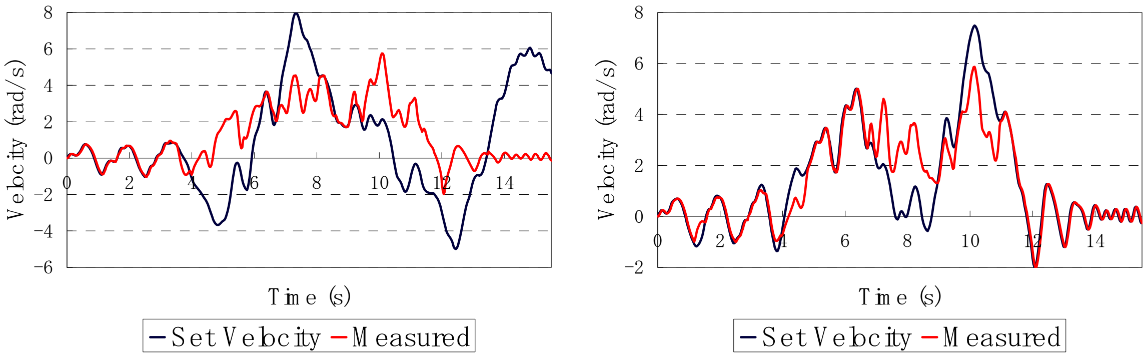
Left Wheel Right Wheel

Fig. 15. Velocity set and measured for each Wheel with 5000 Gain



Left Wheel Right Wheel

Fig. 16. Velocity set and measured for each Wheel with 7000 Gain



Left Wheel Right Wheel

Fig. 17. Velocity set and measured for each Wheel with 10000 Gain

5. Conclusion and Futurework

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. As expected, the walking was unstable due to the effect of external forces created from the arm rest. By using the velocity control in the control system of the simulation, the robot is able to walk stably with the walking assist machine.

In the near future, it is important to develop WABIAN-2R system to be stabilized during walking. The stabilization control will be based on Zero Moment Point. Moreover, it is necessary to develop the robot to interact with other objects and equipments. This will make the robot can interact with its surrounding environment.

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This book book is a collection of 18 chapters written by internationally recognized experts and well-known professionals of the field. Chapters contribute to diverse facets of contemporary robotics and autonomous systems. The volume is organized in four thematic parts according to the main subjects, regarding the recent advances in the contemporary robotics. The first thematic topics of the book are devoted to the theoretical issues. This includes development of algorithms for automatic trajectory generation using redudancy resolution scheme, intelligent algorithms for robotic grasping, modelling approach for reactive mode handling of flexible manufacturing and design of an advanced controller for robot manipulators. The second part of the book deals with different aspects of robot calibration and sensing. This includes a geometric and treshold calibration of a multiple robotic line-vision system, robot-based inline 2D/3D quality monitoring using picture-giving and laser triangulation, and a study on prospective polymer composite materials for flexible tactile sensors. The third part addresses issues of mobile robots and multi-agent systems, including SLAM of mobile robots based on fusion of odometry and visual data, configuration of a localization system by a team of mobile robots, development of generic real-time motion controller for differential mobile robots, control of fuel cells of mobile robots, modelling of omni-directional wheeled-based robots, building of hunter- hybrid tracking environment, as well as design of a cooperative control in distributed population-based multi-agent approach. The fourth part presents recent approaches and results in humanoid and bioinspirative robotics. It deals with design of adaptive control of anthropomorphic biped gait, building of dynamic-based simulation for humanoid robot walking, building controller for perceptual motor control dynamics of humans and biomimetic approach to control mechatronic structure using smart materials.

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