Design of a Biped Robot Using DSP and FPGA

Sung-nam Oh, Sung-Ui Lee, and Kab-ll Kim

Abstract: A biped robot should be designed to be an effective mechanical structure and have smaller hardware system if it is to be a stand-alone structure. This paper shows the design methodology of a biped robot controller using FPGA(Field Programmable Gate Array). A hardware system consists of DSP(Digital Signal Processor) as the main CPU, and FPGA as the motor controller. By using FPGA, more flexible hardware system has been achieved, and more compact and simple controller has been designed..

Keywords: Biped robot, FPGA, DSP.

1. INTRODUCTION

Studies on biped robots have been continually carried out in robotics areas since the 1970's to provide robots in dangerous environments, similar to those which human beings would be normally in. The biped robot can be used without a special change to the working environment because it has similar movements to those of human being. Study on biped robots has been generally executed in two areas on actual manufacturing and performance improvement and on simulation and theory.

In this study, with respect to the actual manufacturing and the performance improvement, Kato and his researchers have successfully created the first walking biped robot, WL-5. Now, through more advanced studies, a humanroid called WABIAN was created [3,5]. Zheng conducted a study in which his robot SD 2 walks on flat surface, walks up stairs and ramps by using 4 hip joints and 4 ankle joints [1,2,4]. The more advanced study on robot is conducted by Honda. They introduced ASIMO which walks almost the same as human.

This lab implemented the biped walking with low power using MBR-S1 (Myong-ji Biped Robot-Static Walking) in 1999, the biped walking up the stairs using MBR-S2, the upgraded model of MBR-S1 in 2000, and the biped fast walking using MBR-F, with an architecture different from those of MBR-S1 and MBR-S2 [6-8]. In the fast walking of MBR-F, the reducing structure for the upper body is needed to solve the problems of fast walking and moment compensation. To reduce the structure of the upper body, we used FPGA, and anew model of a biped robot using FPGA named MBR-3 was designed. MBR-3 has a total of 12 DOF. As a 12 DOF biped robot, MBR-3 can walk more like human beings.

2. The CONFIGURATION of MBR-3

2.1. The overall system

We have designed the overall hardware system using DSP and FPGA. DSP controls the overall system by obtaining the motor's position values from the computer. FPGA generates PWM (Pulse Width Modulation) due to the control of each motor. We have used a RC servo motor for the position control of each joint. The configuration of the overall system is shown in Fig.1.

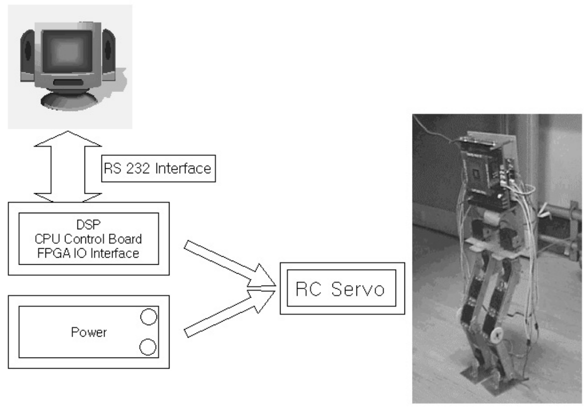

Fig. 1. Configuration of the overall system.

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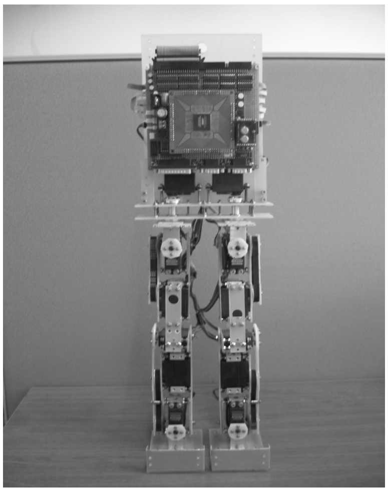

Fig. 2. MBR-3.

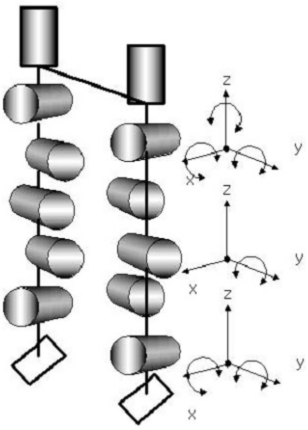

Fig. 3. Link structure of MBR-3.

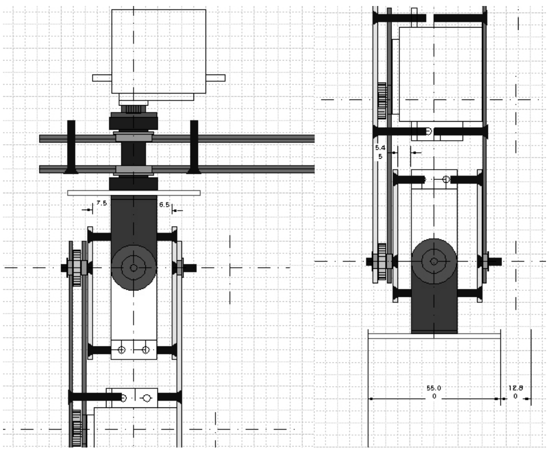

Fig. 4. Joint structure of MBR-3.

2.2. Mechanic structure

The mechanic structure of MBR-3 is shown in the Fig. 2. The biped robotMBR-3 consists of 12 joints and 9 links. The height of the robot's leg is 32.5cm. The total height of a robot when it stands on two feet is 55cm and the total weight is 2 kg including the weight of batteries. Link structure is divided into three parts with a waist, knee and ankle. As mentioned earlier, MBR-3 has totally 12 DOF(-) 6 DOF at the waist, 2 DOF at the knee and 4 DOF at the ankle. The time belt is used for delivering power from link to joint and 6 DOF at the waist enables a robot to rotate from front to rear, and from left to right to compensate for a total balance during walking without using a balanced pendulum.

2.2.1 Link structure

MBR-3 consists of 9 links; 4 links for each leg, and 1 link for the waist. we used FRP for a link structure to reduce weight. Fig. 3 shows the link structure.

2.2.2 Joint structure

When a biped robot is designed, the joint is very important. Fig. 4 shows the waist and ankle of MBR-3. In the waist, the upper motor operating the movements from front to rear is directly connected to each link, and the lower motor operating the movements from left to right is connected to the time belt. Therefore, the upper and lower motors are actually working at the same point by using the time belt. In the ankle, the structure of an ankle joint is equal to that of the waist joint. Also, a robot rotates by the waist joint. Therefore, a robot can walk more like human beings. In view of the structural interpretation, we have realized the simplicity of the interpretation and stability of the walking without a balanced pendulum.

3. CONTROL OF A BIPED ROBOT

3.1. Design of the controller and I/O

DSP(TMS320C50) is the processor of this system. Its machine cycle is between 20-40MIPS so data processing is faster than that of another processor. But this processor the I/O ports generating PWM for the motors. We need a pulse signal for motor control. Using FPGA, we have solved this problem. FPGA is used as a series of ALTERA EPF10K.

3.1.1 PWM for using FPGA

To work efficiently, the controller should be small, simple, and fast. Also I/O and PWM are needed to control the motor. We used the RC servo motor. Its PWM is different of that of DC motor. The motor motion ranges from +90 to -90. And T_h(High Level Time) must be in the range of 0.7-2.3msec.

Fig. 5 shows the pluses for a RC servo motor. Controlling 12 motors simultaneously using. PWM is difficult. Accordingly, we used FPGA to solve this problem. The inside architecture of the designed FPGA is shown in Fig. 6. It consists of several modules. These modules are programmed by

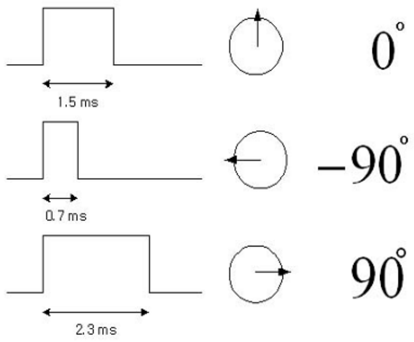

Fig. 5. PWM for a RC servo.

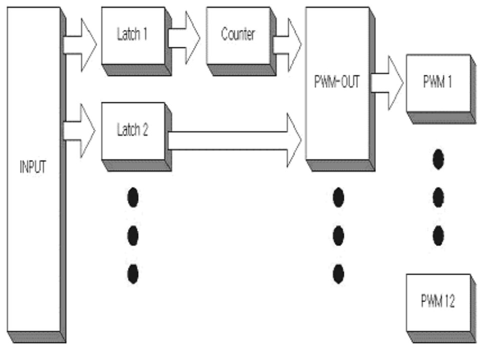

Fig. 6. The inside structure of FPGA.

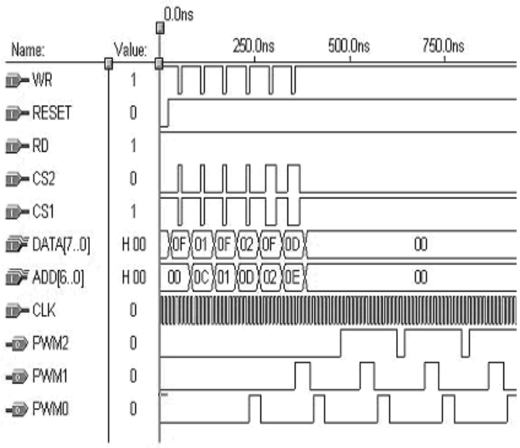

Fig. 7. Simulation of FPGA.

VHDL and MAXPLUS Ⅱ 9.23. In the Fig. 6, input module gives a total period(T) to latch1 module and High Level Time(T_h) to latch2 module. T_h indicates a degree of the motor's movement. PWM_OUT module, a comparator, makes its output values zero when the output values of counter module and latch2 are same. By repeating this processing, we can make a variety of desired pluses. Therefore, we can control all the motors by just one controller. Fig. 7 shows the simulation of FPGA.

3.1.2 Control method

Fig. 8 shows the hierarchical configuration of the biped control system. The top-level PC in this hierarchical controller structure calculates the data in the walking gait and considers the degree of stability. It downloads this information to each joint controller through RS-232 protocol. The controller based on these data changes to suitable values for each joint and these values is transferred to each motor through FPGA.

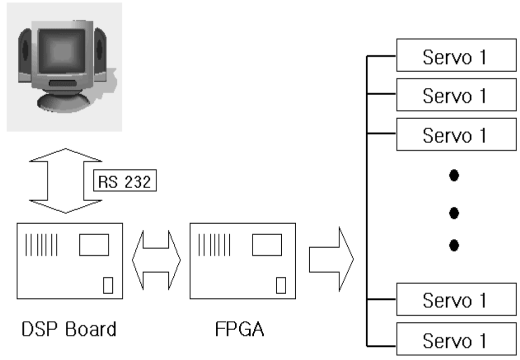

Fig. 8. Hierarchical structure of the biped control system.

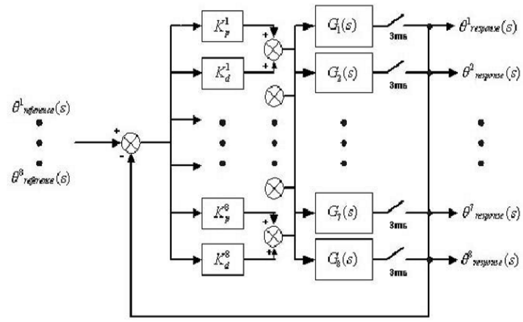

Fig. 9. Block diagram of the PD controller.

3.2. Control algorithm

In general, multi-joint robots, such as biped robots, use PID controllers to obtain exact position controlling and stable controller outputs. However, this study used a PD controller because the vibration by I factor may make the biped robot system unstable. The configuration of the controller is shown in the Fig. 9.

4. DISCRIMINATION OF THE DEGREE OF STABILITY

There are two gaits: static and dynamic. In a static gait, VPCG (Vertically projected point of the center of gravity) always exists within the stable area to keep the stable posture when the robot walks. Otherwise, its interpretation is a little difference with static gait. (ED-unclear) In a dynamic gait, ZMP (Zero point moment) always exists within the foot support area when the biped is walking fast, that is, to walk without falling. VPCG of the robot can be expressed by using the VPCG of each link as shown in the formula (1).

$$VPCG(t) = \frac{1}{M}\sum_{i=1}^{M} m_i \; {}_{VPCG\ i}(t) \qquad (1)$$

Where M is the total weight of the biped robot, m_i is the weight of the link, including the weight of the motor. In addition, VPCG i(t) is the VPCG of the ith link.

5. EXPERIMENT

The biped robot's walking consists of the repetition of a specific gait type. Thus, it is possible to separate the repeated specific gait type into several partial movements, calculate the location value of the actuator for each partial movements, and create the walking data. Fig. 10 shows the partial movements of straight walking. In this case, the biped walks using the joints excepting for those of the rotation axis. (ED-unclear) Walking consists of a total of 19 partial movements, and successive walking is possible by repeating the steps from step.4 to step.15. Fig. 11 shows the partial movements of rotation walking. By the rotation axis, (ED-unclear) the biped robot is made use of the turning around all the directions. (ED-unclear) Walking consists of a total of 18 partial movements, and rotation walking is possible by repeating the steps from step5-step14.

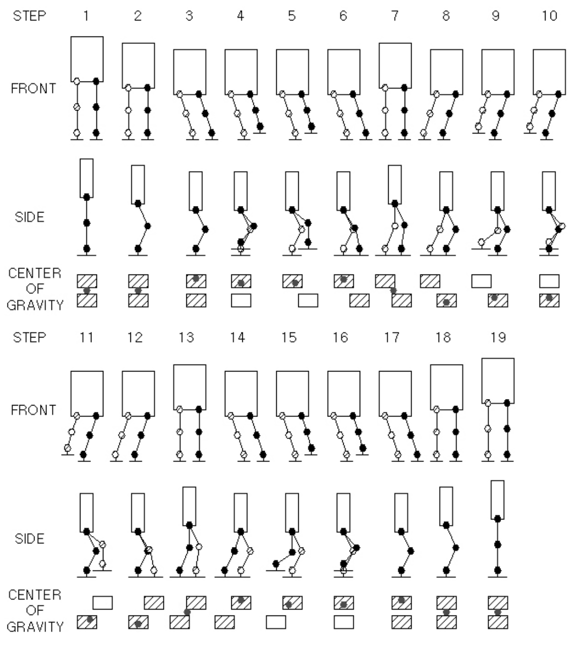

Fig. 10. Partial movements of straight walking.

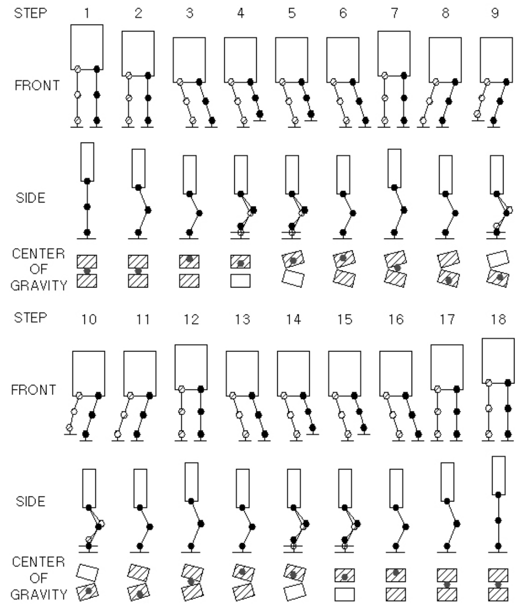

Fig. 11. Partial movements of rotation walking.

6. CONCLUSION AND FUTURE ASSIGNMENT

In this paper, we solved two problems of MBR-F. First, the controller is designed by using FPGA to operate all the joints. Second, an overload problem of fast balanced pendulum movement and moment compensation problem of fast leg movement is solved by adding to the upper body. For future work, make the robot walk in an unstructured environment, we have to use the vision and gyro sensor system.

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