Mechanism and Motion of New Biped Leg Machine

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Abstract

This paper describes the mechanism of a new biped machine capable of doing human-robot cooperation work. The biped machine, WABIAN-2 is made of two seven degrees of freedom (DOF) legs, a two DOF waist and no DOF trunk. Its leg system consists of two three DOF ankles, two one DOF knees and two three DOF hips to deal with various walk motions. Its height is about 1.2[m], and its weight is 40[kg]. It is designed with large movable range as a human. Also, a knee stretch walk pattern generation for the biped machine to perform natural walk like a human is discussed in this paper. Its leg motion is compensated by using the motion of its waist. Basic knee stretch walk experiments using WABIAN-2 are conducted on the plane, and the validity of its mechanism and walk pattern generator is verified.

1. Introduction

Biped humanoid robots are expected to be used not only into industrial areas, but also into non-industrial areas, such as to services in homes and offices and for social welfare. To date, we have studied biped-walking motion with two main thrusts to apply the biped robots to the fields. One thrust has been toward realizing dynamic complete walking on not only even or uneven terrain but also hard or soft terrain. In 1973, we developed WABOT-1 that consists of a torso, a perceptual system and two artificial arms and legs. The biped robot realized the static walking on a horizontal plane [1]. In 1980, we realized the quasi-dynamic complete walking by using WL series. In 1984, the complete dynamic walking with the walking speed 1.3[s/step] was realized by using the program control and the sequence control [2]. In addition, the dynamic walking on the uneven terrain like stairs and inclined planes was realized by modifying a preset walking pattern.

The other thrust has been toward exploring robot-environment interaction and applying to medical and welfare fields. The dynamic biped walking was achieved under the unknown external forces applied by an environment in 1989 [3]. The emotional motion of the biped robot was presented in 1999, which is expressed by the parameterization of its body motion [4]. Also, a battery powered biped locomotor, WL-15, was developed in 2002, which consists of parallel mechanisms [5]. The parallel mechanism consists of six 1-DOF active linear actuators. The robots were designed for multi-purpose use, for example, welfare and entertainment. An aluminum chair was mounted on its pelvis. It performed dynamic biped walk carrying a human for the first time in the world.

Recently, many other research groups have studied on the mechanism of biped walking robots. Aoyama Gakuin University constructed a compact size humanoid robot, MK-5 in 2000 [6]. It has 24 DOF such as 6 DOF in each leg, 5 DOF in each arm and 2 DOF in the head. Its weight is 1.9[kg], and its height is 3.56[m]. University of Tokyo developed H7 in 2001 [7]. It has 30 DOF such as 6 DOF in each leg, 6 DOF in each arm, 1 DOF in each hand, 1 DOF in each foot and 2 DOF in the head. Its weight is 55[kg], and its height is 1.47[m]. Ministry of economy, trade and industry (METI) of Japan developed HRP-2P (prototype of HRP-2) in 2003 which has the capabilities to walk on a plane and to lie down and get up on a floor [8, 9]. It consists of 30 mechanical DOF such as 6 DOF in each leg, 6 DOF in each arm, 1 DOF in each hand, 2 DOF in the neck and 2 DOF in the waist. Its height is 1.58[m], and its weight is 58[kg]. Sony developed SDR-4X II (Sony dream robot, a prototype) with 0.58[m] height and 7[kg] weight in 2004 [10]. It consists of 38 DOF such as 6 DOF in each leg, 5 DOF in each arm, 5 DOF in each hand, 4 DOF in the head and 2 DOF in the waist.

It is difficult for the conventional biped robots to perform natural walk like a human. The reason is that they could not do knee stretch walk in a single support phase. So, we have constructed a new biped machine, WABIAN-2, that consists of two seven DOF legs, a two DOF waist and no DOF trunk. This robot can perform various walk motions such stretch walk and zigzag walk using the redundant motion of the legs. In this paper, we describe the mechanism of WABIAN-2 and stretch walk pattern generation for smooth and natural walking [11, 12]. The generated leg motion is compensated by the motion of the waist. This paper is organized as follows. Section 2 describes a leg mechanism capable of achieving various walk motions. Section 3 describes stretch walk pattern generation. Section 4 shows basic experimental results. Finally, Section 5 provides conclusions.

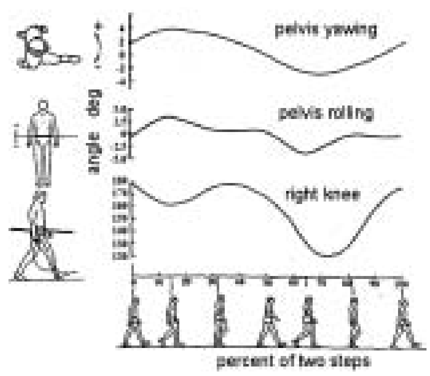


Figure 1: Pelvis and knee motion of a human

2. Mechanism of New Biped Machine

2.1 Mechanical Design

To realize various walk motions like a human, a joint configuration of conventional biped humanoid robots should be changed. Some researchers have studied on the gate analysis of humans [13]. Figure 1 shows the pelvis and the knee motion of humans plotted in the steady walk phase. The waist motion of a human in steady walking is observed in frontal plane (roll motion) and horizontal plane (yaw motion) as shown in Figure 1. The waist motion in sagittal plane (pitch motion) is shown a little as shown Figure 2. It is necessary for a biped humanoid robot to independently have the roll and yaw motion of the waist according to the trunk motion (see Figure 2). If the waist of a biped humanoid robot is constructed as two joints or more, it will be able to perform human-like walk such as knee stretch walk, zigzag walk and so on.

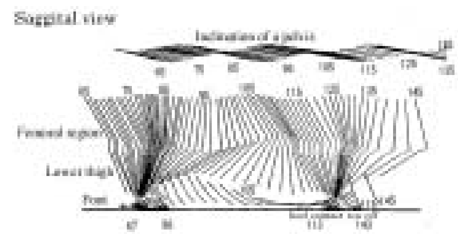


Figure 2: Stick diagram of human hip and leg motion

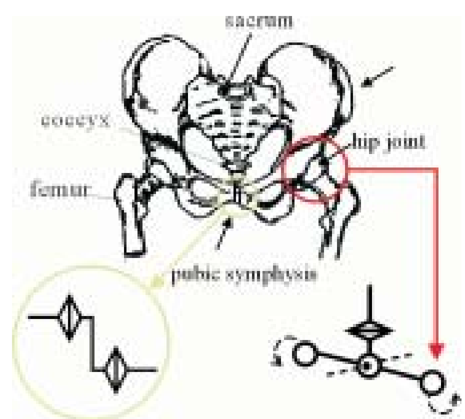
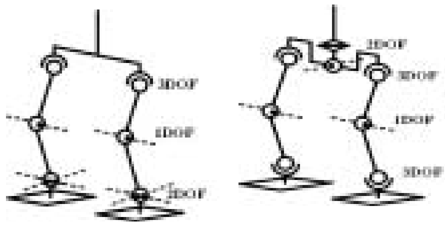


Figure 3: Human pelvis

The ankles of almost all conventional biped humanoid robots consist of the pitch and the roll axes as shown in Figure 4(a). They are difficult to walk stably on hilly and rugged terrain. If a biped humanoid robot has three DOF ankles (a pitch, a roll and a yaw joint), it will be able to select a stable position and reduce the impact and/or contact forces produced between the landing foot and the ground by using a proper control algorithm.

So, we have developed a new biped machine, WABIAN-2, for human-robot coexistence that has two three DOF ankles, two one DOF knees, two three DOF hips, a two DOF waist and no DOF trunk as shown in



(a) Conventional biped (a) New biped

Figure 4: Leg configuration

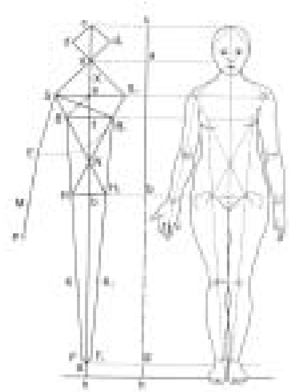


Figure 6: Structure of a human body by a schmidt method

Figure 4(b). The roll and yaw axes of its waist are perpendicular to one another in the center of the pelvis for easy kinematics and a small pelvis structure. Using its leg redundancy, it will be able to climb a ladder, ride something, work in a narrow place and so on as shown in Figure 5. Its height is about 1.2[m] and its weight is 40[kg]. It is designed on the basis of a schmidt method that uses to measure and analyze the form of a human body in view of appearance and cooperativeness (see Figure 6). It mainly employs Duralumin as structural materials. For a compact body and light weight, a new drive system of WABIAN-2 is developed as shown in Figure 7. The combination of a timing belt and harmonic drive gear is employed as a high performance speed reducer. A force/torque sensor is equipped between each ankle and foot to measure the impact/contact force. Its link sizes are shown in Figure 8. Figure 9 shows a photo of WABIAN-2. Table 1 shows the movable range of joints of WABIAN-2 in comparison with human joints. As shown in Table 1, WABIAN-2 will be able to perform various motion like a human using the large movable range of each joint.

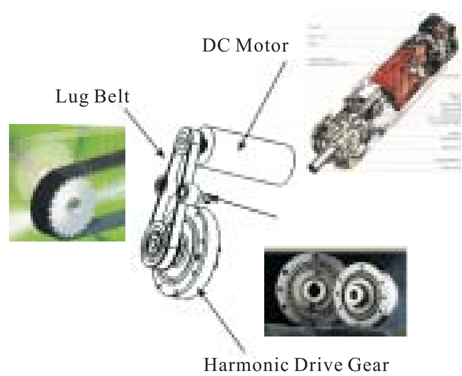


Figure 7: Drive system of WABIAN-2

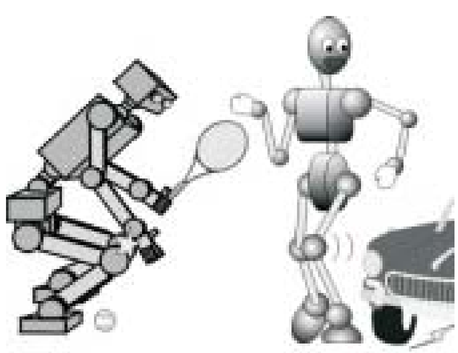


Figure 5: Difficult leg motion

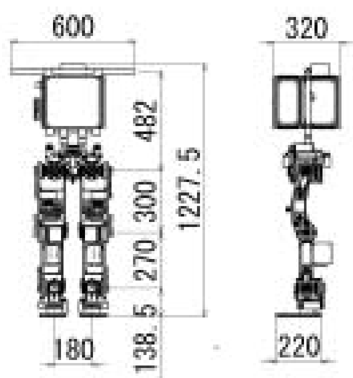


Figure 8: Link size of WABIAN-2

Figure 9: Structure of WABIAN-2

2.2 Electrical Design

WABIAN-2 is controlled by a PC/AT compatible CPU board (an Intel Pentium III, 1.26[MHz]). Its operating system is QNX that enables the execution of realtime processes. The feature of QNX is essential for the identical controller of robot systems. A PCI backplane board with five slots (PCM-PCM05) is used to connect a CPU board and an I/O board. As an I/O board, a Ritech interface board is employed which has a 12ch A/D board, a 16ch D/A board, a 16ch counter board, a 16ch PI/O board. The motors, encoders, accelerations, force/torques sensors and photomicrosensors installed in WABIAN-2 are controlled by the PCI board. Also, as servo drivers, Titech robot drivers (PC-0121-1) are used. Figure 10 shows the control system of WABIAN-2.

3. Knee Strstch Walk Pattern

The conventional walk pattern generator has created, based on the position and orientation of the foot and the waist. This walk pattern generator cannot generate a knee stretch walk pattern because of singular problems of biped legs. So, a new walk pattern generator is developed which is able to make a knee stretch walk pattern.

The world coordinate frame is defined on the ground where the biped robot can walk as shown in Figure 11. The moving frame is fixed on the ankle of the supporting leg to get the relative motion of the particles. In single support phase, the singularity of the swing leg is avoided by the motion of the roll waist. The detail procedure of the pattern generation is as follows: (1) the position and orientation of the foot, knee and waist are set as initial parameters. (2) the horizontal position of the hip of the supporting leg is calculated using the position and the orientation of the waist. (3) each joint angle of the swing leg is calculated by inverse kinematics depending on the foot position and orientation.

3.1 Knee Stretch Walk Experiment

As an experimental procedure, a complete walk pattern is generated at first in an outside computer. This complete walk pattern should include a waist motion pattern to cancel moments generated by the mo-

Table 1: Movable range of each joint.

Joint	Movable angle deg
Right yaw ankle	-10∼+20/-90∼+90
Right roll ankle	-20∼+30/-25∼+40
Right pitch ankle	-45∼+25/-33∼+118
Right pitch knee	-0∼+130/-50∼+160
Right pitch hip	-15∼+125/-98∼+100
Right roll hip	-20∼+45/-22∼+22
Right yaw hip	-45∼+45/-25∼+97
Roll waist	-5∼+5/-18∼+18
Pitch waist	-5∼+5/-45∼+45

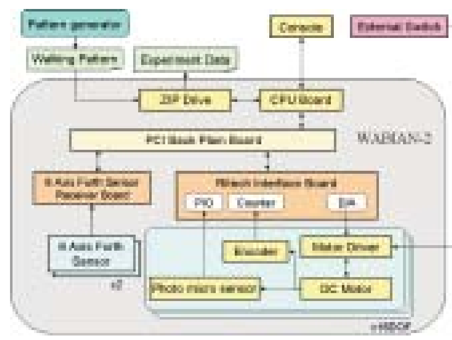


Figure 10: Structure of WABIAN-2

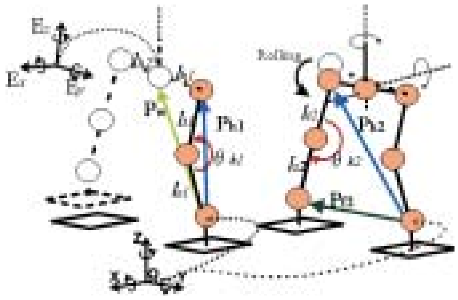


Figure 11: Coordinate frames

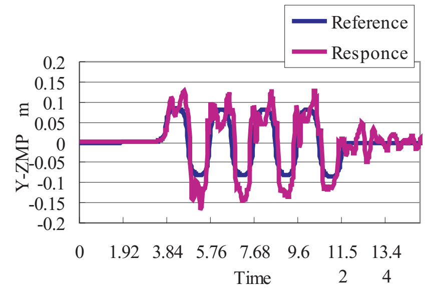
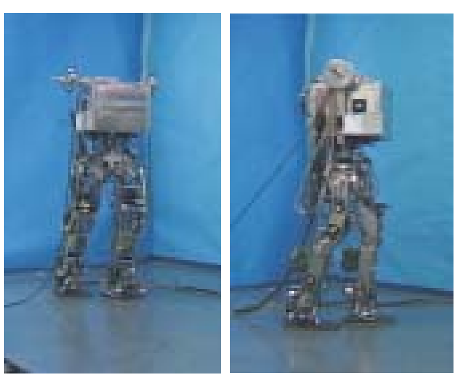


Figure 13: Experimental result: ZMP trajectories

tion of the legs. Then, the main computer reads the walk pattern through ZIP and commands it to motor drivers through a D/A board as shown in Figure 10.

To confirm the effectiveness of the mechanism and the pattern generator of WABIAN-2, knee stretch walk experiments are carried out on a horizontal plane. A step cycle is 0.96[s/step], and a step height is 0.04[m]. Five different step lengths (0.00[m], 0.05[m], 0.10[m], 0.15[m] and 0.20[m]) are used in the experiments.

In experiments, all knee stretch walk motions are realized stably. Figure 12 shows a scene of the knee stretch walk motion with a step length of 0.2[m/step]. Figure 13 shows the desired Y-ZMP trajectory and the Y-ZMP trajectory measured by the force/torque sensors. We can see in Figure 13 that the measured ZMP trajectory is much not deviated from the desired ZMP trajectory.



(a) Front view (b) Side view

Figure 12: Scene of knee stretch walk experiment

4. Conclusion

A new leg mechanism was presented to achieve various walk motions such as knee stretch walk motion and zigzag walk motion. The leg machine is composed of two three DOF ankles, two one DOF knees, two three DOF hips and no DOF trunk. Also, a knee-stretch walk pattern generator is discussed which can be avoid singular problems. Knee stretch walk experiments are conducted on the horizontal plane using WABIAN-2, and the validity of its mechanism and walk pattern generator is verified.

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