Development of biped robot using ultrasonic motor (Fundamental experiment of bending for dynamic walking)

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Many studies have been conducted on development of biped robots, for realizing humanoid robots, since 1980 s. However, most of the robots have no pelvic joint, and require enormous energy for holding own posture at bended knee joints. This paper describes a biped robot considered human pelvic joint using ultrasonic motors. Ultrasonic motors have some special unique features, such as high-torque under low-speed operation, compact size, and no electromagnetic noise. Therefore, ultrasonic motors are expected to apply actuators for biped robots with pelvic joint. We manufactured for a trial robot (composed one leg) using ultrasonic motors. And we confirmed that the proposed robot could flex and extend on the fundamental experiment.

Keywords- biped robot; pelvic joint; ultrasonic motor.

1. Introduction

Biped robots are favorable to work in the living envi-ronment of human, because they move same as human. Therefore, biped robots are have been studied extensively for development of humanoids: robots like human, based on progress of computer technologies.

The studies of biped robots have begun since 1980s for realizing humanoid robot. Miyazaki and Arimoto have proposed the control method for an inverted pendulum model using an actual biped locomotion model with many degrees of freedom (D.O.F.)[1]. Sano and Furusho have showed a 3D dynamic walk control of a biped robot using the its angular [2]. Yamaguchi et al. have studied a biped robot walking control method for adapting to an unknown uneven surface [3]. Yoshino has derived a stabilizing con-troller for high-speed biped walking robot, using optimal regulator theories [4]. Thus, many studies of biped robots have done in both of theory and experiment. Now, ASIMO [5], QRIO [6] and so on have developed in many companies, universities, colleges, and organizations.

However, the most of biped robots walk with small vertical motion at the pelvic joint. From this cause, the knees must be always bent, and require enormous energy for holding own posture at bended knee joints. Human walk with vertical motion at the pelvic joint skillfully, in the different way of such robots. If using this structure around the hip of a biped robot, the smooth walking operation can be realized and the energy efficiency is much better.

The actuators that are used for most of the robots are electromagnetic motors at present. Electromagnetic motors have better controllability than other actuators, although they have a low-torque characteristic under high-speed operation. The use of electromagnetic motors with speed reduction gears as actuators of biped robots with pelvic joint is difficult because of too many large actuators. Therefore, we have focused on ultrasonic motors that have a high-torque characteristic under low-speed operation, compact size and no electromagnetic noise [7]. Using ultrasonic motors as actuators, a biped robot with pelvic joint would realize walking more stably.

In this study, we investigated the manufacture and the experiment of a trial robot using ultrasonic motors.

2. Walking Motion of Human and Biped Robot

Human walks using two legs and the energy efficiency is very high. In the course of evolution, human and other life has obtained the adaptive body structure for walking, walking patterns, and high-energy efficiencies. They were made by the skeletal muscles, which have very high performance. Developing a biped robot, it is very important that to analyze these characteristics in detail. To make a biped robot walking, the robot requires actuators with characteristics like human muscle. Therefore, it is necessary to develop an actuator with lightweight, high controllability, high responsibility, and high output. On that basis, if the biped robot have same as human body and walk using two legs, it is possible to realize humanoid robots that can coexist in the living environment of human.

On most of the biped robots at present, both legs fixed straight downward as the lower half of the body. The ro-bots using such a mechanism walk with no vertical motion at the hip part. The walking method is unnatural compared with human.

Using a movement that the hip goes alternately up and down on either side, and takes a balance of the upper body, when human walks. In case of this walking, landing one leg, it bends the knee a little, and to support own weight with one leg, after it stretches the knee and begins to kick down. The hip seesaws in the process. Thus, the human walking with moving the hip flexibly is due to the structure around the hip. The motion of a human walking is shown in figure 1 [8].

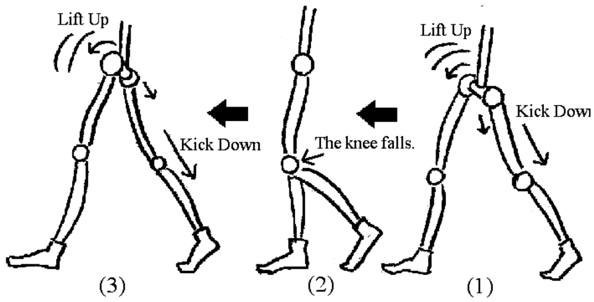

Fig.1 The motion of a human walking using stick model

3. Principle of Ultrasonic Motor

A stator and a rotor are coupled to form an ultrasonic motor. The rotor is pressed against the side of the stator metal surface, which the piezoelectric ceramic is not glued on. The rotor is pressed tightly against this side of the sta-tor metal surface so that they are adhered together closely [9]. The structure of an ultrasonic motor is shown in figure 2.

As a progressive wave travels and undulates through this contact surface, the vertexes of the wave contact some areas of the surface of the rotor that is tightly adhered to the stator and some areas are not.

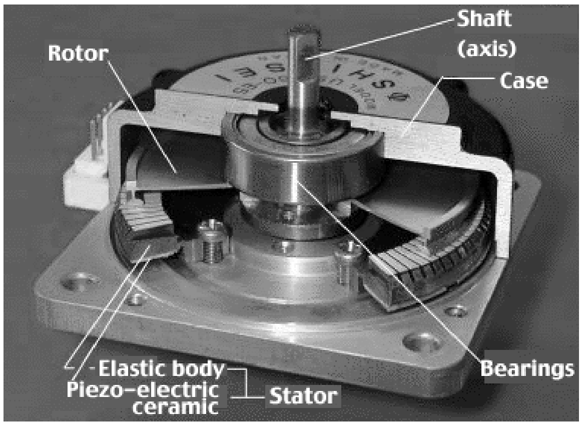

Fig.2 The structure of an ultrasonic motor

Affected by this elliptic rotary motion, the rotor is impelled to rotate. As the direction of the locus of the elliptic motion is opposite to the direction of the progressive wave, the rotor affected by it also rotates in the opposite direction of the progressive wave. When the progressive wave travels along the circumference of the stator clockwise (CW), a counterclock-wise (CCW) elliptic rotary motion is generated at the vertex of the wave contacting the rotor surface. The rotor contacting the vertex is impelled by the CCW elliptic rotary motion and rotates CCW. The motion of an ultrasonic motor is shown in figure 3.

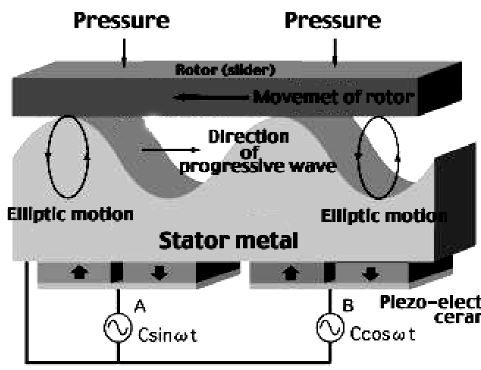

Fig.3 The motion of an ultrasonic motor

4. Biped Robot Using Ultrasonic Motors

The proposed biped robot to develop in this study, arranges ultrasonic motors around the axis of each joint.

4.1 Concept of the proposed biped robot

In order to walking like human, the proposed robot has 14 D.O.F: the 12 D.O.F. at the joint of two legs, and the 2 D.O.F. at the pelvic joint. The D.O.F. of the proposed robot is shown in figure 4.

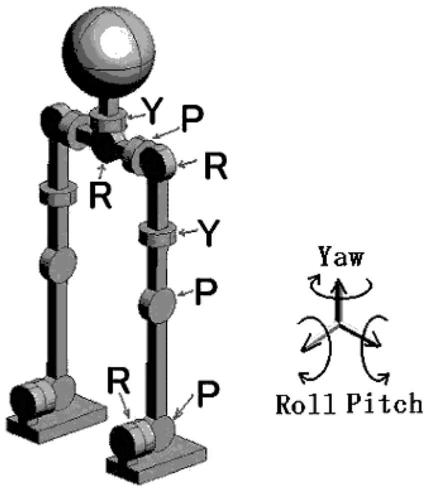

Fig.4 The D.O.F of the proposed biped robot

4.2 Actuator

As actuators of the proposed robot, we use Shinsei USR30-B3 and USR30-B4 (expressed USR30 since then). The specification of a USR30 is shown in table 1. And the specification of a driver circuit D6030 dedicated to drive USR30 series is denoted in table 2.

Table.1 Specification of USR30-B3, B4

Driving Frequency	50 [kHz]
Driving Voltage	110 [Vrms]
Rated Torque	0.5 [kgf-cm]
Rated Output	1.0 [W]
Rated Revolution	200 [rpm]
Maximum Torque	1.0 [kgf-cm]
Holding Torque	1.0 [kgf-cm]
Temperature	263-328 [K]
Weight	20 [g]

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Table.2 Specification of D6030

Voltage Supply	24 [V]
Current Supply	0.7 [Amax]
Oscillation Frequency	50 [kHz]
Oscillation Wave	Pseudo-sin-wave
Voltage of Speed Change	0-3.2 [V]
Revolution (no load)	30-300 [rpm]
Starting Response	50 [ms]
Stopping Response	1 [ms]
Weight	105 [g]

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4.3 Real-time control system for ultrasonic motors

To control of ultrasonic motors, we use the real-time control system that has been developed [10]. The system is shown in figure 5. This system is predominantly comprised of personal computer, interface board, potentiometer, and ultrasonic motor. The control operation system is RT-Linux. Using this system, plural ultrasonic motors can be controlled in real-time.

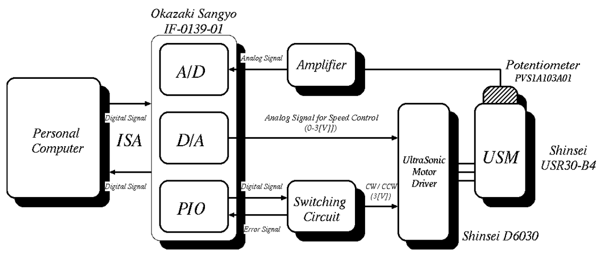


Fig.5 The real-time control system for ultrasonic motors

5. Dedign of Biped Robot

To realize the proposed biped robot, we designed and analyzed a cad model of the robot using ultrasonic motor.

5.1 Cad model of the biped robot

We designed a cad model of the proposed model. The cad model is shown in figure 6. The joints around the ankle, the knee, and the hip, which needs the walking torque, arrange two USR30's in parallel [11].

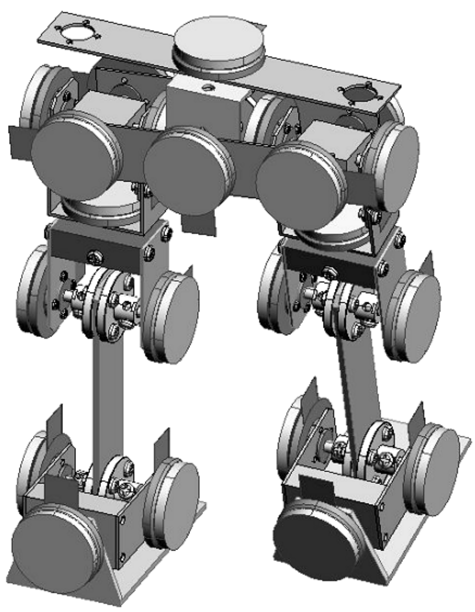


Fig.6 The cad model of the proposed biped robot

Nogai and Koyama's method is a mechanism of ultrasonic motor composed one rotor and two stators [12]. According to this mechanism, the joints around the ankle, the knee, and the hip, which needs the walking torque, are arranged two USR30's in parallel driving. Figure 7 shows the knee joint using parallel driving mechanism on the designed robot.

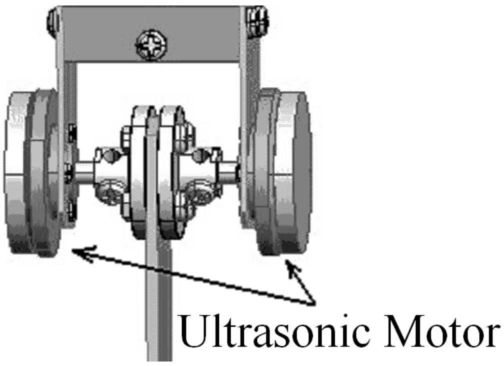


Fig.7 The cad model of the proposed biped robot

5.2 Calucration of requred torque for biped robot

Using this cad model and kinematics, two kinds of load torques at the ankle, the value of bending the knee and the value of maximum, were calculated. The symbols to use are shown in figure 8, where the weight of tibia is M_1 [kg] and the weight of femur is M_2 [kg].

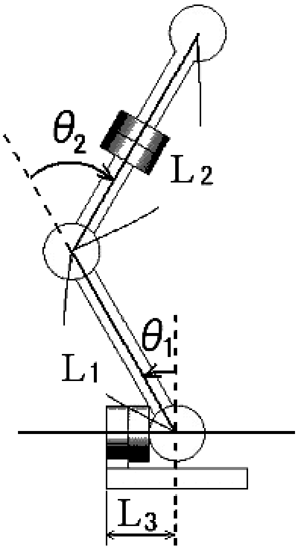


Fig.8 The model of the biped robot for calucration

In figure 8, the load torque at the ankle when bending knee（$\theta_1=\pi/4$，$\theta_2=\pi/2$）; T follows as:

$$T=\frac{1}{2}M_1L_1\sin\theta_1 + M_2\left\{L_1\sin\theta_1-\frac{1}{2}L_2\cos\left(\frac{\pi}{2}+\theta_1-\theta_2\right)\right\} \qquad (1)$$

The maximum load torque at the ankle; follows as: T_{max}

$$T_{max}=(M_1+M_2)L_3 \qquad (2)$$

The calculations are shown in table 3. The maximum torque of USR30 is 1.0[kgf-cm]. On the theory, it is possible to drive with single unit but by installing in parallel of two, the more stable walking can be expected in realty.

Table.3 Requred torque at the ankle of the robot

	Required torque [kgf-cm]
Load torque when bending knee	0.38
Maximum load torque	0.58

6. Manufacturing of Trial Robot and Fundamental Experiment

We manufactured a trial robot composed one leg, and carried out a fundamental experiment using the robot.

6.1 Trial robot

A trial robot, which measures 174[mm] heights, and 240[g] weights, was manufactured based on the cad model. Then, an experiment system for the trial robot was constructed with real-time control system. The overview of the experiment system is shown in figure 9.

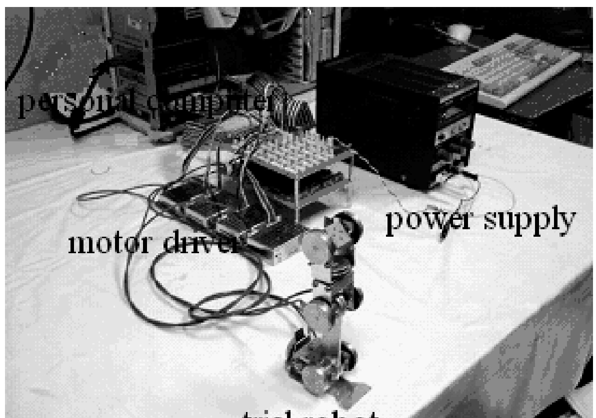
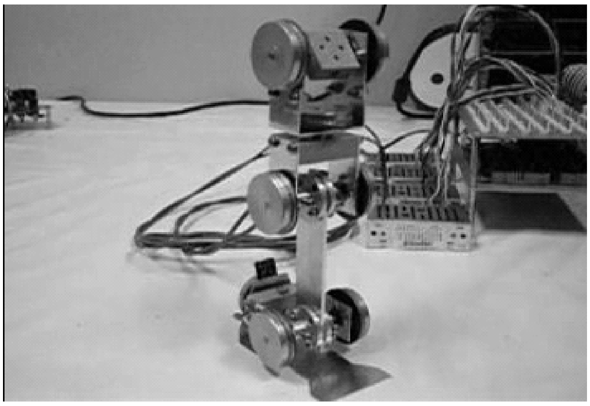
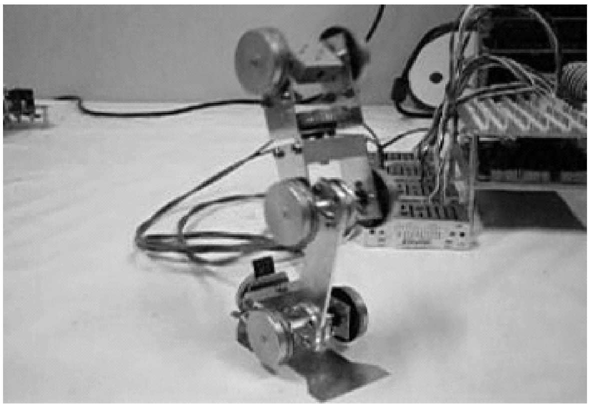


Fig.9 The experiment system for the trial robot



(A)



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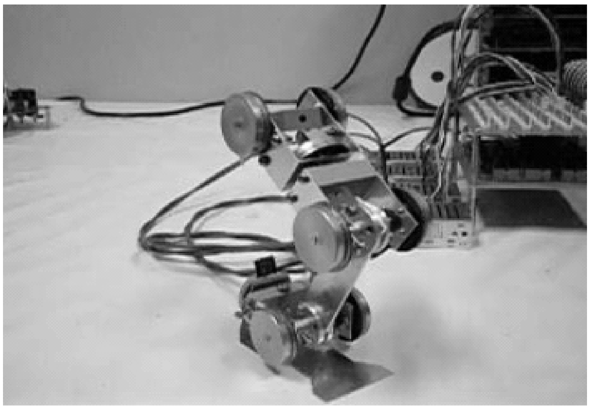
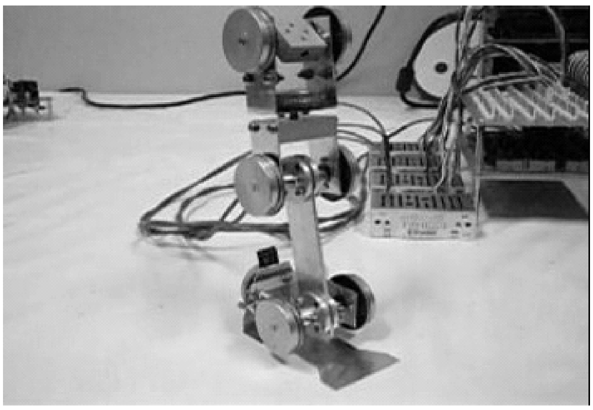


(C)



(D)

Fig.10 The flexing and extending motions of the trial robot

6.2 Checking of operations for the trial robot

We checked of operation for flexing and extending motions of the trial robot. The checking of operation for the robot is shown in figure 10.

We observed that the control signals from the personal computer are reflected in the operation of ultrasonic motors, and the ultrasonic motors keep posture of the robot. Thus, we confirmed an effect on ultrasonic motors used as actuators of biped robots.

7. Conclusion

In this study, we designed a biped robot considered human pelvic joint. Then, we manufactured a trial robot using ultrasonic motors and carried out a fundamental experiment. The experiment shows an effect on ultrasonic motors used as actuators of biped robots.

However, any effects as biped robots were not confirmed because the one leg robot using ultrasonic motor has been only manufactured at present. Therefore, it is necessary to accomplish manufacture of the immature biped robot, and to construct control theories and walking patterns for the robot.

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