A NEW METHOD OF MECHANISM SYNTHESIS FOR BIPED ROBOTS[①]

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ABSTRACT For a biped robot, the most essential components are its joints, including hip, knee, and ankle joints. In this paper, the construction method of a new type of joint is proposed. The main feature of this joint is that a combined transmission consisting of harmonic gear drive and planet gear drive is adopted in its system, and it possesses smaller volume, greater driving torque, and fine-looking appearance. Using this type of joint, a practical biped robot named NAIWR-I was constructed. Experiments with NAIWR-I robot showed that the method of mechanism synthesis proposed in this paper was reasonable and feasible.

Key words biped robot mechanism synthesis harmonic gear drive planet gear drive

1 INTRODUCTION

There are three basic principles in the mechanism syntheses of biped robots. The first is that a constructed biped robot should be able to adjust the positions of its center-of-gravity in the sagittal plane and the frontal plane so that it can walk stablely. The second is that a constructed biped robot should possess enough degrees of freedom so that it can walk flexibly in a structured or unstructured environment with various gaits. The third is that a constructed biped robot should have the capability to bear a heavier load (which means the ratio of load to robot′s weight should be raised as great as possible) so that manipulators, varieties of internal and external sensors, control system, and energy supply device can be installed on it. Among these problems (principles), the first and second ones have been solved basically, but the third problem has not been solved very well as yet. The main method to raise the ratio of load to robot′s weight is improving the structures of joint systems. Up to now, for the most motor-driven biped robots developed in the world, in their joint systems, except motors and measuring sensors, the mechanical parts are harmonic drive[1, 2] or ordinary gear drive[3, 4] or the combined drive consisting of the harmonic drive and the ordinary gear drive[5]. The drawback of harmonic drive is that the joint driving torque is smaller when the joint size is limited in a smaller volume. The shortcoming of ordinary gear drive is that the motor is not on the axis of the joint so that the joint rotational inertia is increased, its servo performance goes worse, and the robot′s appearance is not fine-looking.

The emphasis of this paper is placed on improving the structures of joint systems. The construction method of a new type of joint, in which a combined transmission consisting of harmonic gear drive and planet gear drive is adopted, will be proposed.

2 STRUCTURE OF THE NEW TYPE OF JOINT SYSTEM

The new type of joint system consists of a

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DC torque motor, a harmonic gear mechanism, a planet gear mechanism, and a potentiometer, in which the harmonic and planet mechanisms are used not only as the main body of the joint but also as the speed reducers of the motor, and the potentiometer is used as the position sensor to detect the actual angle of the joint. The right ankle joint was taken as an example to explain the structure of this new type of joint system.

As shown in Fig. 1, the motor and harmonic gear mechanism are linked as a whole. The output axis of the harmonic gear mechanism is the input axis of the planet gear mechanism, and this input axis is fitted into the sun gear A. The foot and the annular gear B of the planet gear mechanism are linked as a whole. The shank, the shell of the harmonic gear mechanism, and the planetary gear carrier H are joined together fixedly. To reduce the volume and weight of the planet gear mechanism, there are four epicyclic gears in it, and in each epicyclic gear an elastic device is mounted so that each epicyclic gear can bear an equal load.

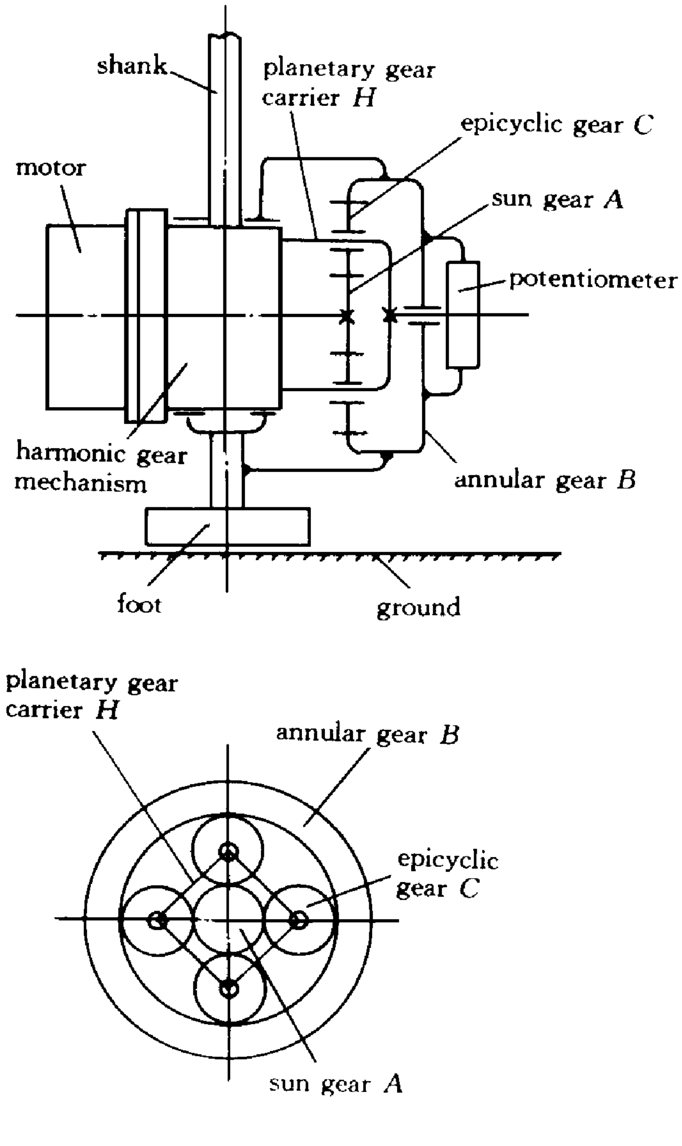

Fig. 1 Structure of the new type of joint system

The motion principle of this joint can be described as follows. If the foot shown in Fig. 1 is swinging foot, when the motor rotates, because the load moment generated by the foot is smaller, the annular gear B is the joint output element of power, and the foot rotates around the joint axis. If the foot is supporting foot, because it is fixed on the ground, the annular gear B can not rotate, when the motor rotates, the planetary gear carrier H is the joint output element of power, the shank and shell of the harmonic gear mechanism rotate around the joint axis.

This new type of joint system can be used not only in the ankle joint but also in the hip or knee joint. By installing one of the joint system on another, we can also construct the compound joint with two degrees of freedom whose axes are orthogonal. If this kind of compound joint is used in the hip, knee, and ankle of a biped robot, it is able to walk in a three-dimensional space.

3 FORMULAS OF THE NEW TYPE OF JOINT SYSTEM

Assuming that the output rotational speed and torque of the harmonic gear mechanism are n_x and M_x respectively, the rotational speeds and output torques of the annular gear B and the planetary gear carrier H are n_b, M_b and n_h, M_h respectively, also assuming that the number of the teeth of the sun gear A is equal to that of the epicyclic gear C, the equations of the new type of joint system can be derived as follows.

If the considered joint is in swinging leg, as mentioned in section 2, the planet gear mechanism will take its annular gear B as the output element of power. In this case, the planet gear mechanism can be regarded as a fixed-axes gear train, and the output rotational speed n_b and driving torque M_b of this joint can be computed by the following equations:

$$n_b = n_x/3 \quad (1)$$

$$M_b = 3M_x \quad (2)$$

If the considered joint is in supporting leg, for example, supposing that it is the ankle joint of supporting leg, as mentioned in section 2, the planet gear mechanism will take its planetary gear carrier H as the output element of power. In this case, because the shank, the shell of the harmonic gear mechanism, and the planetary gear carrier H are linked as a whole, the shank and the shell of the harmonic gear mechanism will also rotate at the rotational speed n_h with the planetary gear carrier H. As a result, an additional rotational speed n_h is added to the output axis of the harmonic gear mechanism. Because n_h has the same rotational direction as n_x, the actual rotational speed of the output axis of the harmonic gear mechanism (it is also the input axis of the planet gear mechanism) is $(n_x + n_h)$ (taking annular gear B of the planet gear mechanism as the reference frame). Fig. 2(a) shows the planet gear mechanism. The rotational speeds of sun gear A and annular gear B are $(n_x + n_h)$ and zero respectively. The center of epicyclic gear C rotates at the rotational speed n_h with the planetary gear carrier H. If the rotational speed $(-n_h)$ is exerted on the planet gear train shown in Fig. 2(a), it is changed into the fixed-axes gear train shown in Fig. 2(b). In Fig. 2(b), because the number of the teeth of annular gear B is three times as great as that of sun gear A, the rotational speed n_h of annular gear B and the rotational speed n_x of sun gear A have the following relationship:

$$n_h = n_x/3 \quad (3)$$

On the other hand, the input power of the planet gear mechanism should be equal to its output power (supposing the power loss of the planet gear mechanism can be neglected), i. e.,

$$M_x(n_x + n_h) = M_h n_h \quad (4)$$

Substituting Eqn. (3) into Eqn. (4) yields

$$M_h = 4M_x \quad (5)$$

Eqns. (3) and (5) are the output rotational speed and driving torque of the joint which is in supporting leg.

From Eqns. (2) and (5), it can be found that the driving torque generated by the new type of joint system is three or four times as great as that of the joint in which only a harmonic gear mechanism is used. Although the planet gear mechanism is used in this new joint system, the joint's weight is not increased greatly because the size of the planet gear mechanism can be limited in a smaller volume.

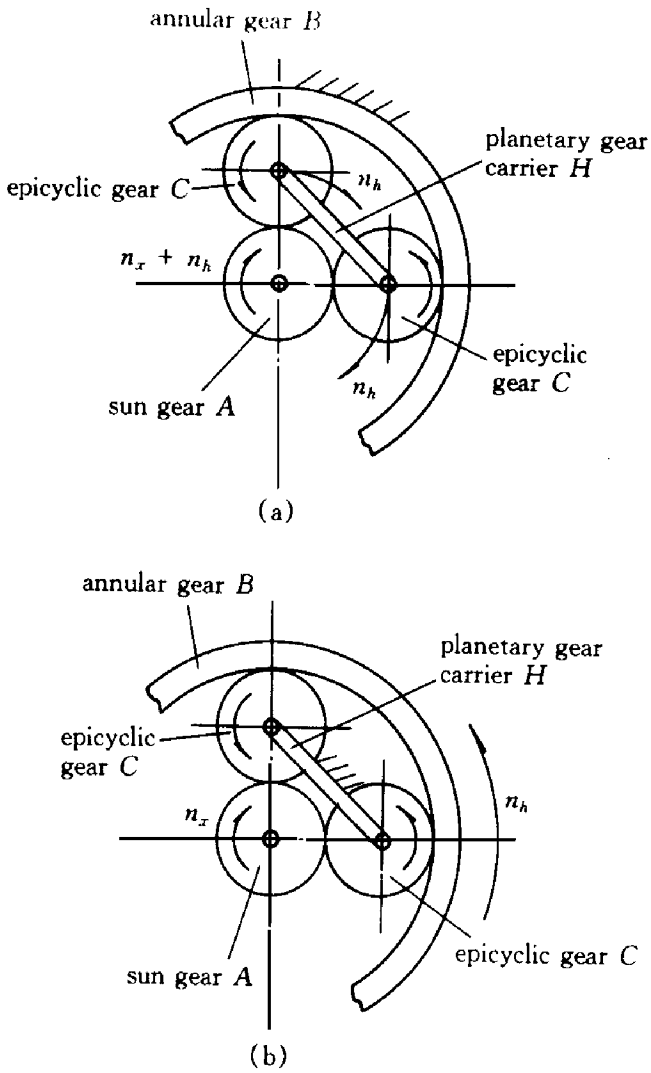

Fig. 2 Formula derivation of the output rotational speed n_h of the joint in supporting leg

4 A PRACTICAL BIPED ROBOT

Using the construction method of joint system proposed in section 2, a practical biped robot named NAIWR-I was constructed at Nanjing University of Aeronautics and Astronautics. It has nine links and eight joints as shown in Fig. 3.

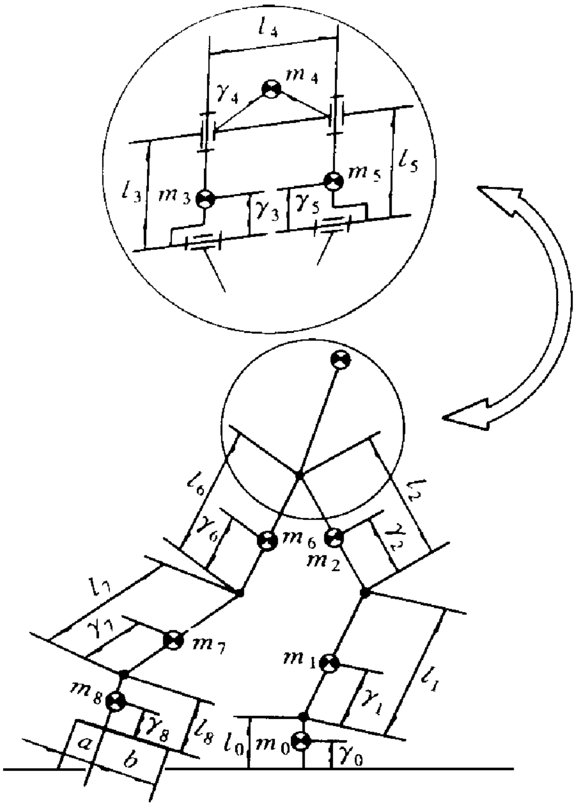

Fig. 3　Structure of NAIWR-I biped robot

The structures of its hip, knee, and ankle joints are the same as that shown in Fig. 1. The weight of each of these joints is about 1.8 kg, and its rated driving torque is 17.625 or 23.536 Nm. On the waist of the biped robot, two joint systems are mounted vertically so that the robot can turn left and right, but in the two joint systems, there are not the planet gear mechanisms because their load torques are smaller.

There are two round bars in each foot of this biped robot (the feet are rectangular), and they stretch out from the foot's inner side. The two round bars of each foot are parallel to the front and back edges of the foot, one is near the tiptoe and another is near the heel. These bars are used to balance the biped robot in walking. On the sole of each foot, two microswitches are installed, one is near the tiptoe and another is near the heel. These microswitches are used to detect the supporting state of the foot.

The parameters of NAIWR-I biped robot are shown in Table 1. Fig. 4 is the photograph of NAIWR-I biped robot.

The computer simulations and static walking experiments on NAIWR-I biped robot were

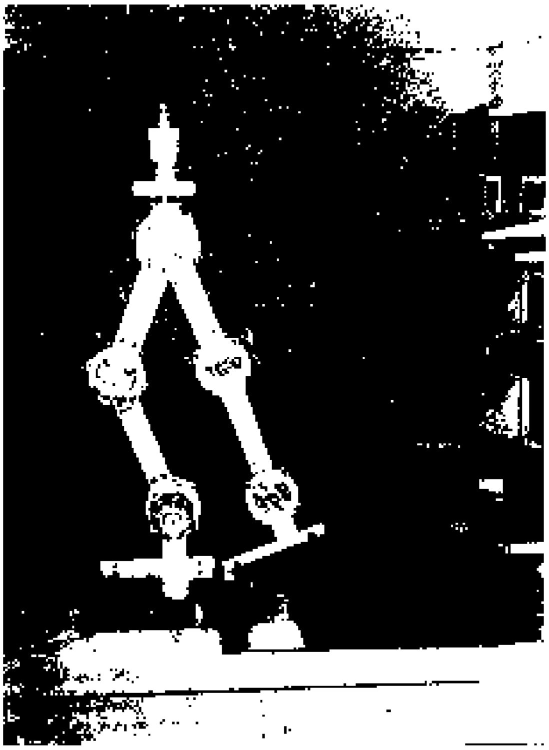

Fig. 4　Photo of NAIWR-I biped robot

Table 1　Parameters of NAIWR-I biped robot

Parameters	Link i								
	0	1	2	3	4	5	6	7	8
Mass m_i/kg	0.888	2.452	2.462	1.841	3.894	1.841	2.462	2.452	0.888
Radius l_i/m	0.100	0.260	0.250	0.089	0.138	0.089	0.250	0.260	0.100
Radius r_i/m	0.056	0.067	0.064	0.008	0.081	0.008	0.064	0.067	0.056
Foot length a /m	0.070	–	–	–	–	–	–	–	0.070
Foot length b /m	0.130	–	–	–	–	–	–	–	0.130

executed. The results can be summarized as follows. If there is no load on the biped robot, the length of each step is greater than 40 cm when it walks on the level ground, and the height of each stair is greater than 10 cm when it goes upstairs. If the biped robot has a load whose weight is 30% of that of the robot(about 6 kg), it can still walk normally. In this circumstance, the length of each step and the height of each stair are not less than 20 cm and 4 cm respectively. These results indicate that NAIWR-I biped robot has a greater ratio of load to its weight.

5 CONCLUSION

From the above study, it can be summarized that the construction method of the new type of joint system proposed in this paper is reasonable and feasible. This new joint system can generate a greater driving torque in a smaller volume. The biped robots constricted by using this joint system can possess the greater capability to bear a heavy load.

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