Curve Walking Method of Master-Slave Quadruped Walking Robot

Shinichi AOSHIMA, Amane MURAO, Masatake SHIRAISHI

Abstract—The real time recognition of environment and the decision of control signal to each actuator are very important for control of the walking robot on rough terrain. Their techniques are not perfect at the present. So, we proposed master-slave quadruped walking robots using radio control devices, which can efficiently use the recognition and control function of human. We have already performed experiments for straight walking using a prototype of a master-slave quadruped walking robot. This robot could walk forward and backward on even terrain, and could get over the low steps. In this paper, we proposed a curve walking method of the master-slave quadruped walking robot, and performed the curve walking experiments. The experimental results showed the validity of the proposed method.

Index terms—Mobile Robot, Walking Robot, Master-Slave, Mechanism, Control, Quadruped Walking

I. Introduction

Many walking robots have developed for mobility of rough terrain [1]-[5]. However, most of them were not used actually. Because mechanisms and control of the walking robot are more difficult than them of the wheel or crawler type mobile robot. The real time recognition of environment and decision of control signal to each actuator are very important for control of the walking robot on rough terrain. Their technique are also not perfect at the present. So, recently, a master-slave walking robot that can use efficiently the recognition and control function of human is studied for a biped walking robot. The master-slave biped walking robot was introduced in a book for a robot 20 years ago [6]. The slave robot was humanoid type to work on the moon. The arms and legs of the slave robot follow the motion of the master. The robot that an master operator get on a slave robot was also developed for biped and quadruped [7], [8], and hexapod walking robot [4].

Various master-slave walking robot have developed as mentioned above. However, master-slave walking robots of a remote control type with legs more than three have not developed. So, we have already proposed master-slave tripod walking [9]. One leg is a stick or a tail for the master-slave tripod walking robot. The main role of them is to keep stability of a posture of the robot. Motions of the other two legs follow the two legs of a master. Moreover, we have already proposed master-slave quadruped walking robots using radio control devices [9]. Then, we also performed the experiment for straight walking. This robot could walk forward and backward on even terrain, and could get over the low steps [10].

In this paper, we first show the proposed master-slave quadruped walking robots of four types. Next, we describe the experimental system for one type that a master is a biped human type and a slave is a quadruped animal type. Then, we propose a curve walking method of this robot. And, some experiments for curve walking are performed using this system. Finally, we describe conclusions and perspective of this robot.

II. Proposal of Master-Slave Quadruped Walking Robot

We propose master-slave quadruped walking robots of four types as shown in Fig.1, and then describe their characteristics. The first type is that both of master and slave are a quadruped animal type. It is hard that a person with a master device makes a posture of a quadruped animal. The person can not understand intuitively a gait of a quadruped animal. The second type is that both of master and slave are crawler type. A posture is easy, a gait can be understood intuitively. The third type is that a master is a human type and a slave is a quadruped animal type. A person with a master device walks commonly by two legs. Then, fore legs of a slave move as legs of a master, a movement of hind legs is determined automatically by a movement of fore legs as the slave robot can walk. However, if there is obstacles on the walking plane, it is difficult to decide a gait of hind legs. The forth type is that a master and a slave are a human type with two stocks. The

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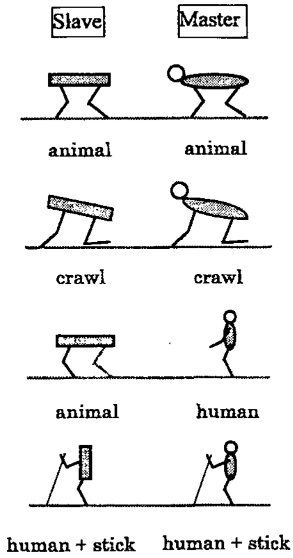

Fig. 1. Master-slave quadruped walking robots of four types.

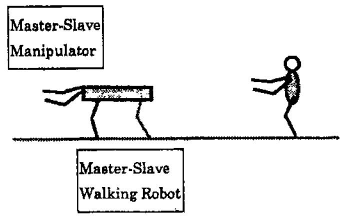

Fig. 2. Walking robot with master-slave manipulator.

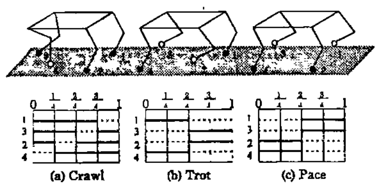

Fig. 3. Three kind of gaits in quadruped walk.

slave robot can keep a straight posture and stability by the stocks. The person can understand intuitively a gait. Because we have experienced the gait at a ski ground.

In this paper, we select the third type as a prototype robot, because motion of the master is nature, and a posture of the slave robot is stable. Moreover, this type can attach a master-slave manipulator for some works to body, because a person of the master can use freely two arms, as shown in Fig.2.

As mentioned above, the master walks commonly by two legs. Then, fore legs of the slave robot follow motion of legs of the master. A gait of the hind legs of the slave robot is automatically decided as the slave robot do a trot gait. Why do we select a trot gait ? In the quadruped walk, there are mainly three kind of gaits: a crawl, a trot and a pace as shown in Fig.3. A crawl is very stable gait. However it is not match a human gait, because a duty ratio of a crawl differs from it of a human gait. On the other hand, duty ratios of a trot and a pace are same as it of a human gait. However, it is difficult for a pace to keep stability because the center of gravity of a body moves to right and left. So, we select a trot as a gait of the master-slave quadruped walking robot.

III. System Construction

In this section, we describe a system construction of a master-slave quadruped walking robot and each device. The system construction of this robot for experiments is shown in Fig.4. We explain a signal flow of this system. First, joint angle values for knees and hips of a master are sent from a transmitter to a receiver. A computer takes these signals by an A/D converter. A D/A converter of the computer sends gait information created from joint angles of a master to a R/C receiver of a slave robot through a R/C transmitters. So, the slave robot walk by servo motors as same as the master robot walk.

Next, we explain each device. Fig.5 shows how to attach joint angle measurement device to knees and hips. The devices consist of potentiometers and sticks. The sticks are fixed legs or hips by bands. A prototype of a slave quadruped walking robot is shown in Fig.6.

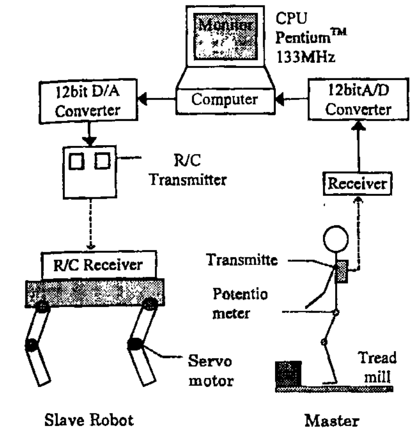

Fig. 4. System construction of this robot for experiments.

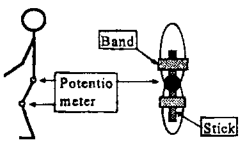

Fig. 5. How to attach joint angle measurement device to knees and hips.

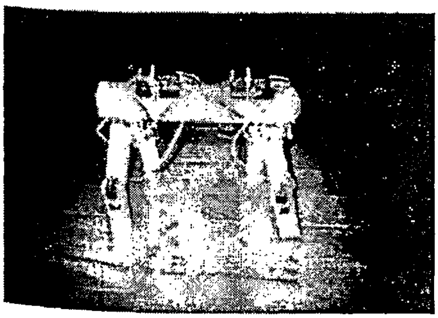

Fig. 6. Prototype of a slave quadruped walking robot.

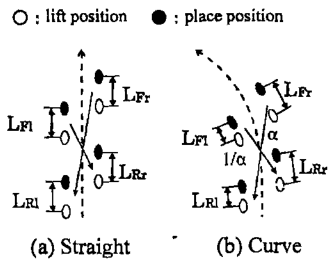

Fig. 7. Method of straight and curve walk.

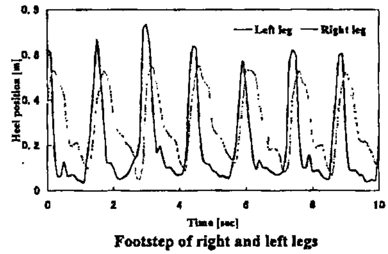

Fig. 8. Footstep of right and left legs.

IV. Method of Straight and Curve Walking

For straight walking, footsteps of right and left are same. Trot gait is also no problem as shown in Fig.7(a). However, in case of left curve, left footsteps must be shorter than right footsteps. We also use trot gait for curve walking. Motion of diagonal legs is same. So, as shown in Fig.7(b), a footstep L_{Rl} must be shorter than L_{Fr}. , and a footstep L_{Rr} must be shorter than L_{Fl}. Therefore, gain α needs between footsteps of right and left. Next, we think how to obtain gain α. If you usually walk along a left curve on even terrain, right footsteps are longer than left. So, you can get gain α as ratio of right and left footsteps. However, in the case of walking on treadmill, if you intend to walk as right footstep is longer than left footstep, right and left steps are almost same. Because you can not utilize a twist of hip on the treadmill. We confirmed this phenomena by the curve walking experiment on the treadmill. This is shown in Fig.8. So, we can not use a ratio of the right and left footsteps as gain α. Therefore, we thought the other method to get gain α. In this method, gain α is ratio of right and left footsteps from hip position line. How to obtain gain α is shown below.

[1] Heel positions X_r and X_l for right and left legs are calculated by the following equation (1), (2).

$$X_r = A\sin(\theta_{1r}-\theta_{2r}) + B\sin\theta_{1r} \quad (1)$$

$$X_l = A\sin(\theta_{1l}-\theta_{2l}) + B\sin\theta_{1l} \quad (2)$$

[2] Maximum values X_{rmax} and X_{lmax} of heel positions X_r and X_l shown in Fig.10 are obtained.

[3] When heel positions X_r and X_l become zero, gains α_r and α_l are calculated by the following equation (3), (4). The gains are alternately calculated as shown in Fig.10.

$$\alpha_r = X_{r\,max}/X_{l\,max} \quad (3)$$

$$\alpha_l = X_{l\,max}/X_{r\,max} \quad (4)$$

where, $\alpha_r > 1$ then $\alpha_r = 1$, $\alpha_l > 1$ then $\alpha_l = 1$

In experiment, gains are digitized by using four gain ranges to avoid frequent change of gains and to keep stable walking. The gains are multiplied to joint angles of each leg of a master as shown in Fig.11. The legs circled in solid or dotted line move in same phase.

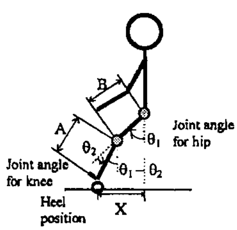

Fig. 9. Definition of heel position.

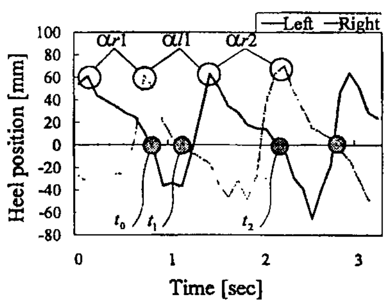

Fig. 10. Relationship between heel positions and gains.

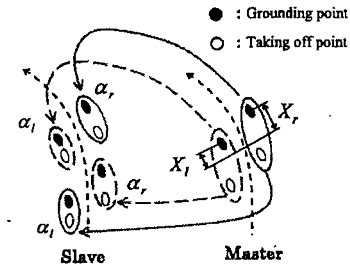

Fig. 11. How to multiply gains.

V. Experiments

We performed experiments for curve walking using a prototype of a master-slave quadruped walking robot. Figure 12 shows a man attached joint angle sensors and a slave robot. The man walks on a room runner device, because of natural walking. Desired walking curve line is shown in Fig.13.

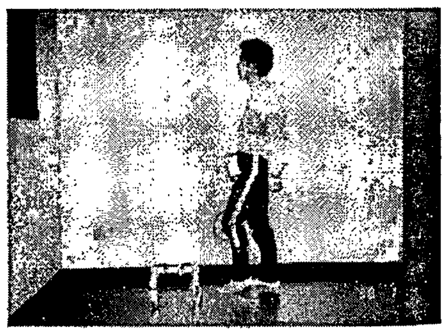

Fig. 12. Man attached joint angle sensors and a slave robot.

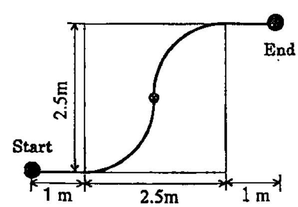

Fig. 13. Desired walking curve line.

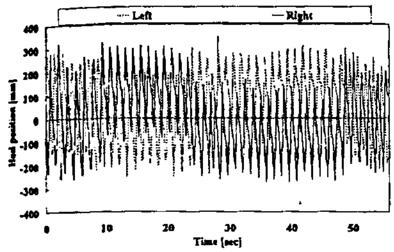

Fig. 14. Heel positions of master.

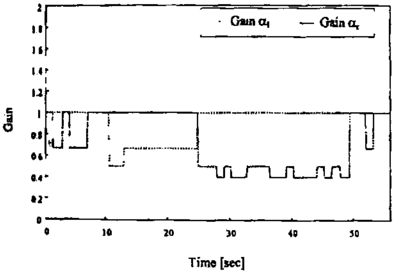

Fig. 15. Gains multiplied to joint angles of master.

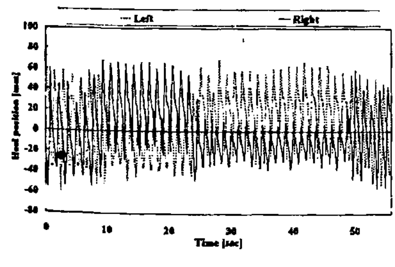

Fig. 16. Front heel positions of slave robot.

The man walks as a slave robot walks along the desired curve line. So, the man must change footsteps of right and left to change the direction of robot, and to reduce the deviation from the desired curve line. Figure 14 shows right and left heel positions of master. The gains multiplied to joint angles of master were calculated by the maximum values of heel position of the master as shown in Fig.15. The footsteps of a slave robot were changed by the gains as shown in Fig.16. The desired walking line consist of a straight line, a left curve line, a right curve line and a straight line. So, there are four gain changing patterns as shown in Fig.15. At the left curve line, gain α_l is smaller than 1. Similarly, at the right curve line, gain α_r is smaller than 1. However, for walking period, a part of right curve line is longer than a part of left curve line. We think that this reason come from a difference between right and left constructions, motor characteristics or master devices. The experiment result of curve walking is shown in Fig.17. The slave robot almost walks along the desired curve line. The man can easily change the direction of robot by changing footsteps of right and left legs.

VI. CONCLUSION

In order to realize the walking on rough terrain, we proposed master-slave quadruped walking robots using radio control devices, which can efficiently use the recognition and control function of human. In this paper, we especially performed the proposal and the experiment for curve walking using a prototype of a master-slave quadruped walking robot. This robot could walk along the desired curve line by only foot operating of a master. The experimental results showed the validity of the proposed curve walking method. Hereafter, we will challenge the problems for stability of a body and force feedback control.

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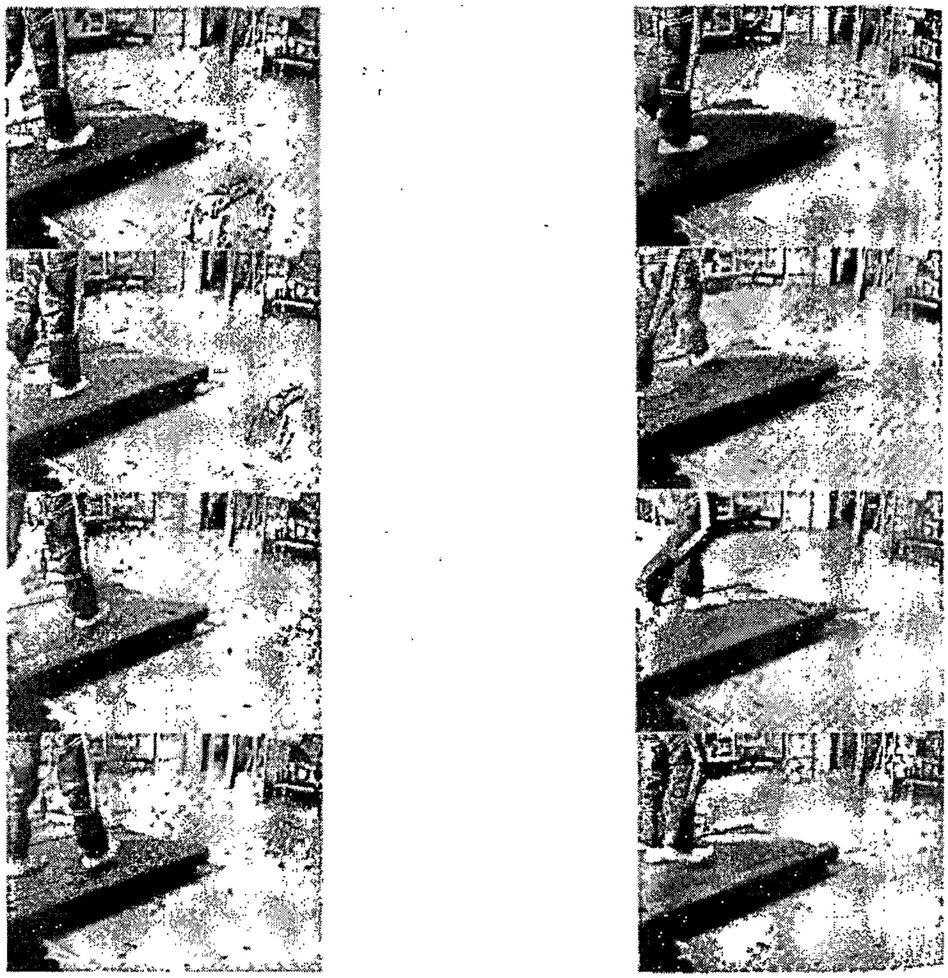

Fig. 17. Experiment of curve walking.