Partial Leg Exchange and Active CG Control of Twin-Frame Walking Machine

Kan YONEDA, Yusuke OTA, Fumitoshi ITO and Shigeo HIROSE

Tokyo Institute of Technology, Department of Mechano-Aerospace Engineering,
2-12-1 O-okayama Meguro-ku, Tokyo 152-8552, JAPAN
{yoneda, ohta, fito, hirose}@hikari.mes.titech.ac.jp

Abstract

In this paper, partial leg exchange gait for twin-frame walking robot is proposed. This twin-frame walking robot doesn't have the degrees of freedom (DOF) for moving the center of gravity (CG). Thus, it is impossible to increase the stability margin actively. But using this proposal method, CG can move in the leg exchange phase and obtain enough stability margins. Proposal gait motion is verified through experiments using mechanical model ParaWalker-II.

1. Introduction

It is desired to be developed the practical robots which have both high terrain adaptability and high manipulability for moving on uneven terrain and performing various tasks. We have been developing twin-frame mobile robot named "ParaWalker-II" as with these abilities [1]. And until now, it is confirmed its practical use through the experiment of walking on uneven terrain [1], force control [2] and stair climbing [3].

In this paper, we propose the partial leg exchange motion, which is the method for obtaining high mobility with keeping high stability. Using this method, the position of CG can be moved during the leg exchange motion. Therefore the wider strides and more mobility can be obtained.

2. Twin-Frame Walking Robot "ParaWalker-II"

The indispensable abilities for practical moving and task performing robot are 1) mobility. 2) ability for performing tasks. and 3) ability for assisting for performing other tasks. As such a robot we proposed the twin-frame mobile robots [4].

Twin-frame mobile robots consist of two frames and 6-DOF mechanism connecting each frames. **Figure 1** shows twin-frame walking robot, which is walking type robot in the category of twin-frame mobile robot, named "ParaWalker-II." ParaWalker-II consists of two frames (leg-bases) with three legs. Each leg-base is connected by 6-DOF mechanism named "S/P Hybrid Platform." Therefore the swing leg-base can be move with 6-DOF motion against the supporting leg-base, that is against the ground. So using this DOF motion, ParaWalker-II has enough task performing abilities shown in **Fig. 1** as a 6-DOF manipulator.

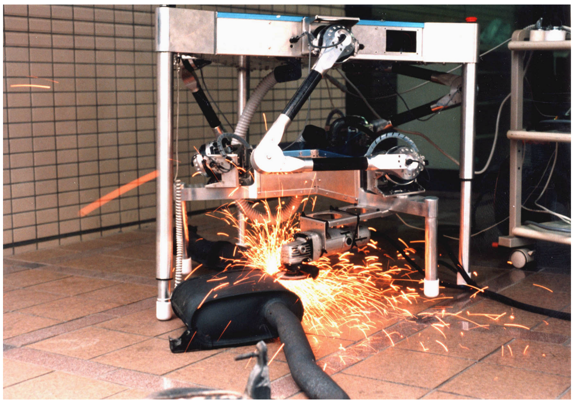


Figure 1: Twin-frame walking robot "ParaWalker-II", which can perform various tasks (performing the grinding task)

And using this DOF motion, ParaWalker-II can produce the walking motion. ParaWalker-II can walk with keeping its stability because each leg-base touch the ground with 3 points (legs) and the CG always stay inside the supporting area that is made by grounded points.

Twin-Frame mobile robot performs both tasking and moving using the same mechanism. So the necessary DOF, that is the actuators, for tasking and moving can be minimized. As a result of this, total weight can be reduced. Furthermore, reduction of DOF, actuators, makes control of the robot easy because amount of necessary calculation for the robots becomes small.

And the ParaWalker-II equips only one extendable leg [3] because of achieving higher terrain adaptability. But this is no relation between this paper. We don't explain and handle in this paper.

3. Partial Leg Exchange Motion

The gait motion for ParaWalker-II is produced by alternate motion. Each leg-base becomes swing/support leg-base alternatively. So this gait motion is equivalent to the biped with wide sole.

In bipedal walking motion like human beings, the position of the CG makes smooth transitions. That is because the smooth CG motion is produced by the motion of the upper part of the body. But the CG motion of twin-frame walking robot ParaWalker-II is intermittent motion. And ParaWalker-II doesn't have extra DOF for moving only CG actively because ParaWalker-II is constructed with minimized DOF. This makes some disadvantages. First, the position of CG is determined by relative position of each leg-bases explicitly. And second, the stability margin, that is almost equivalent to the mobility, is determined by robot's structure. For example in ParaWalker-II, the maximum stride (horizontal distance between each frames) is determined the 400 [mm] by its structural geometry. And if leg exchange motion is carried out at near this stride length the stability margin becomes very small and leg exchange motion is performed unstable. Therefore securing stability margin, one step is limited about 200 [mm] in the case of normal walking motion. Thus, the problem how to obtain high stability in leg exchange phase should be resolved for obtaining higher mobility.

So we proposed partial leg exchange motion. As using this method, the leg exchange motion is performed with high stability margin and robots realize wider strides. Furthermore, this method has the possibility that the robot is also able to move with smooth CG transition that is similar to the movement of the animals. Process of the partial leg exchange motion is explained next.

3.1 Process of the partial leg exchange motion

Motion difference between proposal partial leg exchange motion and previous motion is shown in **Fig. 2**. The process of proposal partial leg exchange motion is:

1: Lift up the frame and go forward
2: Rotate frame centered by frame's CG
3: Down the frame (two legs are touched down)
4: Rotate frame and all legs are touched down

At the process 2, CG doesn't move because center of the rotation is match with the center of frame, that is CG of each frame. At the process 3, grounded point of the leg goes forward with inclination of the frame.

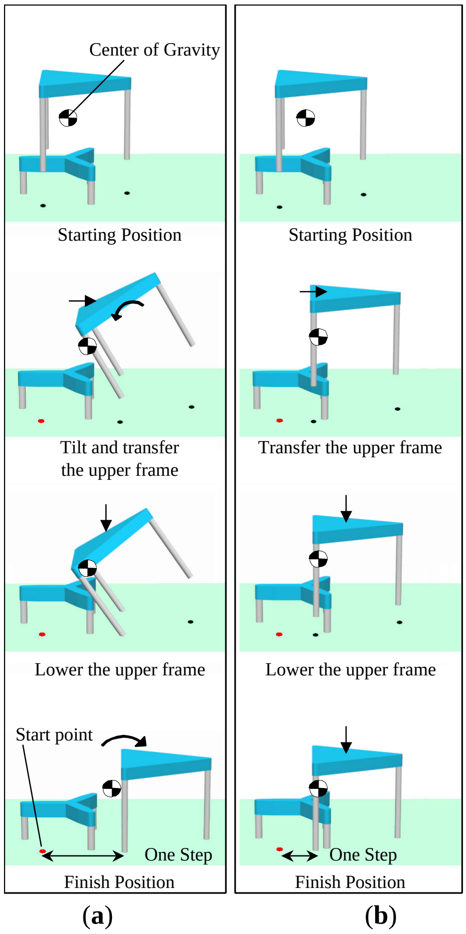


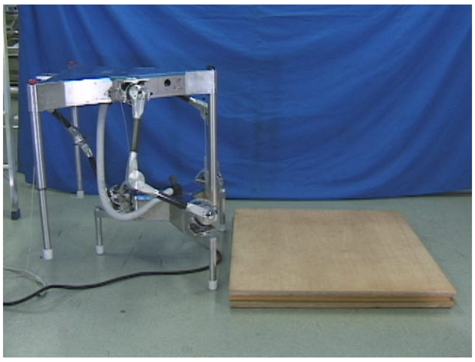
Figure 2: Comparison between
(**a**): proposal partial leg exchange motion and
(**b**): previous normal gait motion

So stride length can be changed by the inclination angle of the frame with the same stability margin. Therefore, it is possible to take a wide stride walk with enough stability margins.

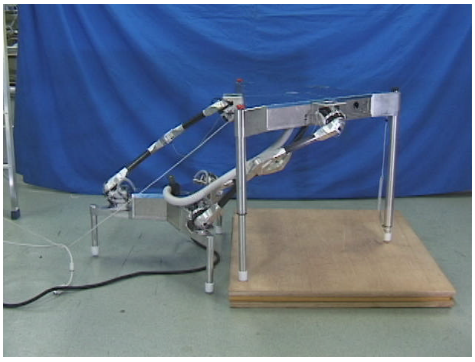
This motion is resemble to animals' walking motion. Animals make their CG move smoothly in walking motion using these sequences, at first touch their heel to the ground, then whole sole and finally only tow. As taking this proposal walking motion the twin-frame walking robot ParaWalker-II can produce the smooth CG transition that was moved alternatively taking the previous walking motion.

4. Walking Experiment

Figure 4 shows the walking experiment using partial leg exchange motion by the ParaWalker-II. This confirms the realization of stable static walk with about 500 [mm] step using partial leg exchange motion.

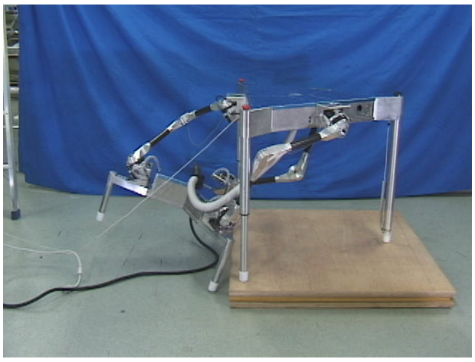


Step1: Lift the upper-leg-base

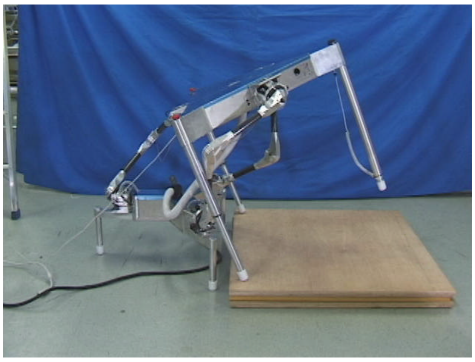


Step4: Rotate the upper-leg-base (all legs are touched down)

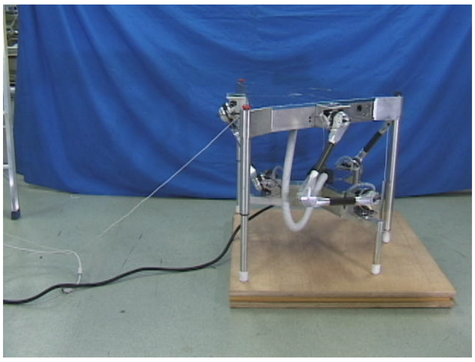
Step2: Forward the upper-leg-base and rotate



Step5: Rotate the lower-leg-base (1 leg left the ground)



Step3: Down the upper-leg-base (2 legs are touched down)



Step6: Lift. rotate, forward and grounded the lower-leg-base

Figure 3: Partial leg exchange walking experiment

5. Applications

5.1 For various walking gait motions

Partial leg exchange motion produces the CG actuation that seems impossible at the leg exchange phase. Therefore, using this motion makes some variations of pattern for walking gait motion.

5.1.1 3-6-3 gait motion (previous normal gait pattern)

This is previous gait motion. This gait sequence is shown in **Fig. 2** (**b**). So the number of the grounded legs changes from 3 to 6 and 3. From the problem of CG position that doesn't go out the supporting area, the state like **Fig.3 step4** cannot be taken. Therefore the maximum stride in this walking motion is limited by about 200 [mm].

5.1.2 3-5-6-5-3 gait motion

This is the partial leg exchange motion shown in **Fig. 3**. The number of grounded point is transfer from 3 to 5, 6, 5, and 3.

5.1.3 3-5-4-5-3 gait motion

This walking motion is shown in **Fig.4**. In this motion, grounded points change from 3 to 5, 4, 5 and 3 without all legs are grounded. As there is no state in all legs are in contact, the CG motion may become smooth and walking velocity could be faster than 3-5-6-5-3 gait motion that is before proposed.

5.1.4 2-4-2 gait motion (dynamic walk)

Furthermore, it is considered that a twin-frame walking robot can make a dynamic walk using an active CG control with 2,4,2 points contact sequence. In this gait, only two contact points of each frame are used, and the gait motion is like a pace or bound gait of quadruped.

5.2 For constructing biped

Since using the partial leg exchange motion, the supporting area is not overlapped. Therefore, supporting area can be taken some distance and produced separately each other. This state is equal to bipedal walking style. The walking motion shown in **Fig. 4** is obviously one type of bipedal walking motion with static balance. This means that the biped that is a twin-frame type structure can be constructed with only 6-DOF taking the strategy as a partial leg exchange motion. This result suggests that the biped, that seems to be necessary of 12 DOF for walking any direction, can be constructed by only 6-DOF.

Therefore, this proposal moving method is efficient as a constructing technique for walking robot with reduced degrees of freedom.

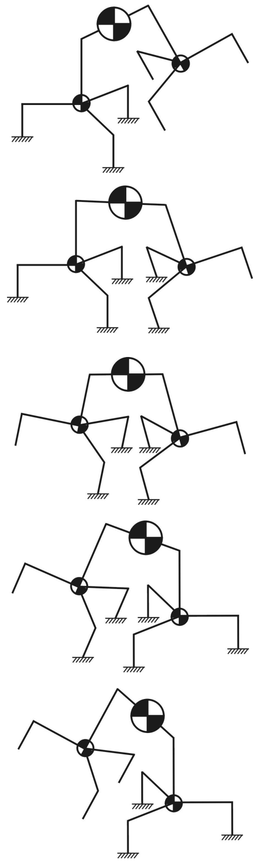


Figure 4: Process of 3-5-4-5-3 gait motion

6. Conclusions

In this paper, the partial leg exchange motion which produces the CG actuation in leg exchange phase is proposed. As using this proposal method ParaWalker-II, that is the twin-frame walking robot that frames are connected by 6-DOF mechanism, is achieved CG transition in leg exchange phase that seems to be difficult, maximum strides with keeping stability and smooth CG motion. And this proposal method is verified through the walking experiment.

As a future work the dynamic walk in our proposal partial leg exchange motions will be applied to the ParaWalker-II.

Acknowledgement

This research is supported by The Grant-in Aid for COE Research Project of Super Mechano-Systems by The Ministry of Education, Science, Sport and Culture.

References

[1] Yusuke OTA, Yoshihiko INAGAKI, Kan YONEDA *and* Shigeo HIROSE; "Research on a Six-Legged Walking Robot with Parallel Mechanism", Proc. of the IROS 98, pp.241-248 (1998)

[2] Yusuke OTA, Kan YONEDA, Shigeo HIROSE *and* Fumitoshi ITO; "Six-Axis Force Control for Walking Robot with Serial/Parallel Hybrid Mechanism", Proc. of IEEE Int.Conf. on Robotics and Automation, pp.1469-1474 (1999)

[3] Kan YONEDA, Fumitoshi ITO, Yusuke OTA *and* Shigeo HIROSE; "Steep Slope Locomotion and Manipulation Mechanism with Minimum Degrees of Freedom", Proc. of the IROS 99, pp.1896-1901 (1999)

[4] Yusuke OTA, Kan YONEDA, Fumitoshi ITO *and* Shigeo HIROSE; "Design Concept for a Walking Machine with Reduced Degree of Freedom", Proc. of 2nd International Workshop and Conference on Climbing and Walking Robots, pp.485-496 (1999)