Consideration on a Crawler Robot with Six Legs

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Abstract

In this study, we consider development of a crawler-type mobile robot which is equipped with six legs at its body. This type of robot may have possibilities of both high mobility on rough terrain and working ability with handling such as carrying an object and removing small obstacles in its movement by using the legs as manipulation arms. This paper presents mechanisms and characteristics of this type of robot and some possible hybrid motions in which crawlers and legs are used. A running motion over a large gap by this type of robot is also considered as a typical hybrid motion with crawlers and legs. Necessary joint-torques of the legs in the motion are also analyzed in a computer simulation.

Keywords: Crawler-type mobile robot, legged robot, hybrid motion, handling task with locomotion, running motion over a gap

1. Introduction

With the recent spate of disasters in the world, the need for robots which can perform rescue activities in a disaster area has been growing. Such rescue-purpose robots should not only move to obtain information but also complete handling tasks by themselves in their working area. Therefore, the robot that has a hybrid mechanism with crawlers and robotic arms is useful because it can perform tasks for manipulation. In fact, some literatures describe that hybrid systems have capabilities of not only locomotion but also performance of work such as handling task.[1]

However, conventional types of robot which has the hybrid mechanism have not been satisfied with both of movement and working ability very much. For example, in leg-wheel hybrid systems, many types such as Roller-Walker[2] and ATHLETE[3] have a wheel at the end of each leg, so these are not suitable due to limitation of the handling task. In case of the mobile robots with leg-crawler hybrid system, even though it has an advanced locomotion ability[4], the mechanism in which a leg itself drives as a crawler[5, 6] may not be suitable for our aim with respect to capability of handling task. A crawler-type robot with four legs presented by Hirose et al.[7] have not been considered on handling tasks very much because movement mechanisms and how to obtain information from the surrounding environment have been mainly focused on. On the other hand, some leg-crawler hybrid robots are considered on some handling work. For instance, HELIOS IX[8] is equipped with a manipulator for rescue operations. However, the type of task and the size of target object are restricted because of its single arm.

We thus consider another type of hybrid mobile robot with crawlers and six legs which are used as manipulators. Basically, in order to achieve stable static walking, six or more legs are necessary.[9] Even though the increase of the number of legs brings the decrease of mobility due to heavy weight and energy consumption, we consider the robot which has six legs is appropriate to the leg-crawler hybrid mobile robot with respect to both locomotion and working abilities.

This paper describes the structure and mechanism of devised crawler-type mobile robot which has six legs. Some possible hybrid motions by crawlers and legs are considered as an advantage of this type of robot. A computer simulation is also performed based on statics to analyze necessary joint-torques of the legs in the running motion over a gap.

2. Crawler-type Mobile Robot with Six Legs

2.1. *Overview*

We have devised a crawler-type mobile robot which has six legs. Fig. 1 shows an overview of the robot. The robot consists of two crawlers and six legs. Three legs are mounted on the left or right side of robot body. Each leg has 4-DOF mechanism and can be used as a manipulator.

This mechanism enables the robot to have high mobility such as running over a large gap by using front and rear legs to support the robot body appropriately, climbing a steep slope by assisting the crawler movement using legs, and so on. In addition to the high mobility, this type of robot is able to perform some useful tasks at a disaster area by acting the legs as manipulators. For example, the robot will be able to remove a small obstacle such as stone on the pathway of the robot in its movement using one leg, carry a large object to destination using multiple legs, get into a large rubble with supporting or removing it using multiple legs and retrieve a target object using the other legs, and so on. Fig. 2 shows a typical example of motion indicating an advantage of the robot; running over a large gap, which normal type of robot is not able to perform, by four legs with carrying a box by two legs.

2.2. *Crawler Mechanisms*

Two crawlers are attached at both sides of the robot body. Each crawler can be made by a belt with attachments and pulleys. One pulley which is at the most front or rear side can acts as a driving pulley by connecting a DC motor. The other pulleys then act as idling pulley. A rotary encoder is also attached to a pulley for the control of crawler movement. The two

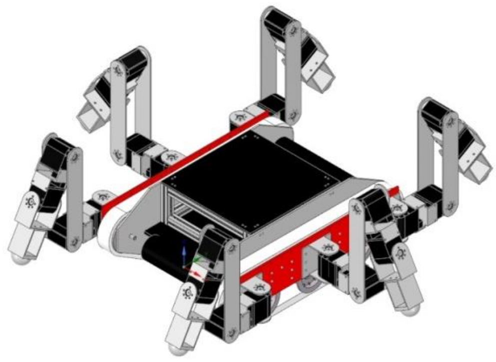

Fig. 1. Overview of crawler-type mobile robot with six legs.

driving pulleys for the left and right crawlers should be located diagonally to balance the body such that the right crawler has a driving pulley at the rear side and the left crawler has it at the front side. Symmetric location of the motors and encoders will enable the robot to run straight stably.

2.3. *Leg Mechanisms*

Fig. 3 shows the mechanism of devised leg. The leg has four joints: two yaw joints (J_1, J_4) and two roll joints (J_2, J_3). This mechanism enables the robot to perform a walking motion using each leg as 3-DOF mechanism by fixing the angle of J_4. On the other hand, the joint J_4 will be used when the robot performs a manipulation task such as carrying an object. Servo motors will be able to be used as joint actuators. These can be selected based on a statics analysis of necessary torques in hybrid locomotion such as running over a gap, which will be presented later.

3. Consideration of Hybrid Running Over Gap

We consider a running over a long gap as a hybrid motion by crawlers and legs with carrying a box by the robot as shown in Fig. 2. If the robot doesn't have nor use legs, the robot will fall in the gap when the center of gravity of main body goes out of the edge of the gap. In this case, however, the presented crawler-type robot is able to use front and rear legs so that the robot prevents falling. Specifically, the robot can ground the tips of front legs on the opposite edge before the center of gravity of the robot come to just above the edge of the gap, continue movement by the crawlers with the

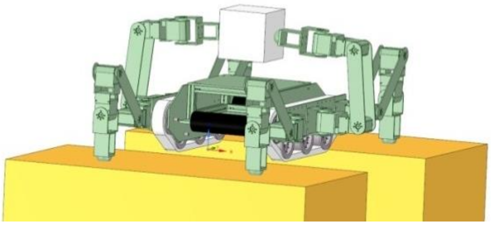

Fig. 2. Running over a large gap with carrying a box by crawler-type mobile robot with six legs.

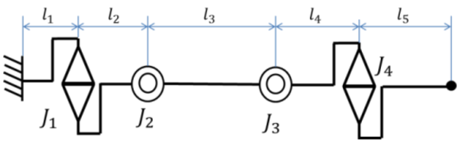

Fig. 3. Mechanism of a leg.

support of the front tips, touch the tips of rear legs at a little behind the edge before the robot body completely comes above the gap, then get across the gap by supporting the body by four legs. When the front part of body touches the ground at the opposite side of the edge, the robot can release the tips of front legs from the ground, then continue running by the crawlers with the support of the rear tips. When the center of gravity of the body comes above the opposite edge of the gap, the robot can release the rear tips and return to normal locomotion using crawlers only. In this motion, the robot doesn't have to use the fourth joint J_4 for each leg so that it acts as 3 DOF.

Let us suppose that the height of ground between the gap is same and the robot moves slowly. The models in this motion in the side view are shown in Fig. 4. We can divide the motion into three states: (a) *front leg auxiliary supporting*, (b) *front and rear legs supporting*, and (c) *rear leg auxiliary supporting*.

In the state of *front leg auxiliary supporting*, the distance between the edge of the gap and the center of gravity of the robot, L, meets $0 \leq L \leq B_h$ where B_h is the length between the center of gravity and the rear end of the body of the robot. In this state, the balance of moment around the edge point of the gap gives

$$Lmg = L_1 F_{zf} \tag{1}$$

where m is the mass of the robot, g is the acceleration of gravity, L_1 is the horizontal distance between the edge

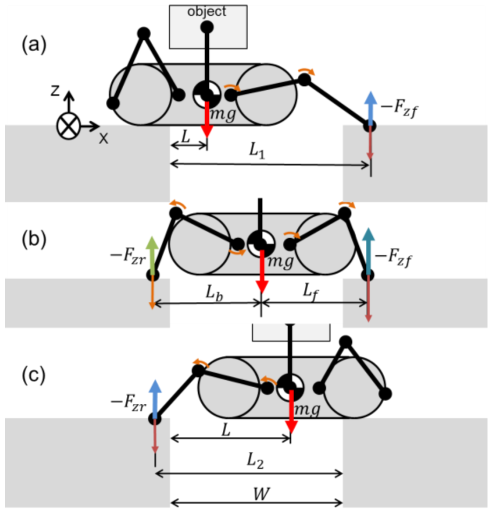

Fig. 4. Models in the motion of running over a gap (a): front leg auxiliary supporting (b): front and rear legs supporting (c): rear leg auxiliary supporting.

of the gap and the contact point of the front tip, and F_{zf} is the vertical component of the force to be generated at the front tip, so reaction force $-F_{zf}$ are acted to the contacting point of the tip.

In the state of *front and rear legs supporting*, because of supporting by four legs, the balances of moment around the both contact points of front and rear tips should be considered. The balance of moment around the rear tip gives

$$F_{zf}(L_r + L_f) = L_b mg, \tag{2}$$

and the balance of moment around the front tip gives

$$F_{zr}(L_r + L_f) = L_f mg \tag{3}$$

where L_f and L_r are the horizontal distances between the center of gravity of the robot and the front and rear contact points respectively, and F_{zr} is the vertical component of the force at the rear tip.

In the state of *rear leg auxiliary supporting*, it meets $(W - B_h) \leq L \leq W$ where W is the horizontal distance of the gap. In this state, the balance of moment around the opposite edge point of the gap gives

$$(W - L)mg = L_2 F_{zr} \tag{4}$$

where F_{zr} is the vertical component of the force at the rear tip and L_2 is the horizontal distance between the front edge of the gap and the contact point of the rear tip.

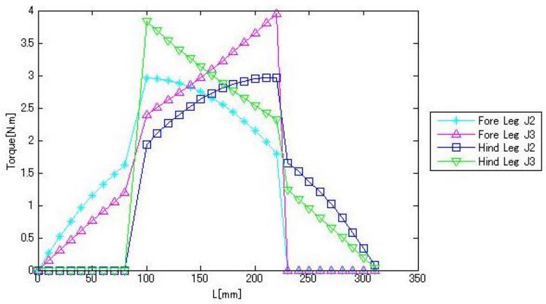

Fig. 5. Joint torques for the front and rear legs in the motion of running over a large gap.

From Eqs. (1)-(4), we can obtain necessary forces at the tips of the front and rear legs, then compute necessary torques for the joints J_1, J_2, and J_3 of each leg, $\boldsymbol{\tau} = (\tau_1, \tau_2, \tau_3)^{\mathrm{T}}$ based on statics by

$$\boldsymbol{\tau} = \boldsymbol{J}^{\mathrm{T}}\boldsymbol{F} \tag{5}$$

where $\boldsymbol{J}$ is Jacobian corresponding to the tip position at each time, and $\boldsymbol{F} = (F_x, F_y, F_z, \tau_x, \tau_y, \tau_z)^{\mathrm{T}}$ is a vector which consists of x, y, z components of the force, F_x, F_y, F_z, and moments around x, y, z axis, τ_x, τ_y, τ_z generated at the tip position.

Fig. 5 shows the computational result of the joint torques for the front and rear legs to L. In this case, we supposed that the distance between the bases of front and rear legs is 150 *mm*, the lengths of five links of each leg shown in Fig. 3 are $l_1 = 45$, $l_2 = 42$, $l_3 = 150$, $l_4 = 68$, *and* $l_5 = 95$ *mm*. $W = 312$ *mm* was also assumed as the distance of the gap. In the result, $0 \leq \mathrm{L} \leq 90$ shows the state of *front leg auxiliary supporting*, $90 \leq \mathrm{L} \leq 226$ shows the state of *front and rear legs supporting*, and $226 \leq \mathrm{L} \leq 312$ shows the state of *rear leg auxiliary supporting*. For each state, F_{zf} or F_{zr} was applied to F_z, and 0 was given the other components of $\boldsymbol{F}$ in Eq. (5). The torque of the first joint is not shown because it was always zero.

From this result, we can select appropriate joint motors which are enough for performing this motion; their maximum torques should be equal to 4 *Nm* at least.

4. Conclusions

In this study, we have considered development of a crawler-type mobile robot which has six legs. Because each leg can be used as a manipulator, the robot is able to perform variety of tasks as well as high mobility. For future work, we plan to develop this type of robot and perform hybrid locomotion and working motions with legs and crawlers.

Acknowledgements

This work was supported by the Ring Ring Project of the JKA Foundation.

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