Bio-inspired Design of a Double-Sided Crawling Robot

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Abstract. A CardBot is a crawler with a thin card-sized structure, which has a limit in crawling when turned upside down. A double-sided CardBot presented in this paper is a robot that can crawl even when it is turned upside down because it can crawl on both sides. By adding one more robot body on a single-sided CardBot and sharing a motor to drive both slider cranks, a low height double-sided robot can be made. This 19 mm high, 26.39 g robot can crawl at a speed of 0.25 m/s. Thanks to the low body height, the robot can explore narrow gaps. Experiments were conducted to compare the running performance between the single-sided CardBot and the double-sided CardBot. Compared with a single-sided CardBot, only little degradation of the performance occurs due to implementation of a double-sided driving. The design has been adapted to reduce the friction, but the weakness of the shared joint due to the interaction of both cranks remains an unsolved problem. The structure of the robot will be modified to provide better performance in the future.

Keywords: Legged locomotion · Double-sided · Hexapod

1 Introduction

Insects in the nature explore diverse and complex terrains. Many robots have been designed for the purpose of exploring regions that are hard to access otherwise by mimicking insects. HAMR^3 [1], DASH [2], DynaRoACH [3], iSprawl [4], Mini-Whegs [5], RHex [6] are the representing crawlers inspired by nature.

When exploring rough terrain, an insect will often find itself turned upside down, and therefore would need the ability to turn itself back to the right position. Usually insects self-right by flapping wings or twisting a body to move the center of mass to a favorable position. Like some insects, robots that have the ability to self-right have recently been developed [7, 8].

Another way to crawl from an inverted position is constructing a structure that can run on both sides. Inspired by creatures that can always land on the right position after

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a fall, a robot has been developed that can run regardless of the direction of landing. A CardBot with a thin card-sized body has been introduced to make a double-sided crawling robot. The robot crawls based on a single-sided slider-crank mechanism. As seen in Fig. 1(b), it consists of a thin body and motors lie on it. The height of a basic robot with one transmission and body is 15 mm. Since having a low height, this robot can pass through low placed narrow gaps.

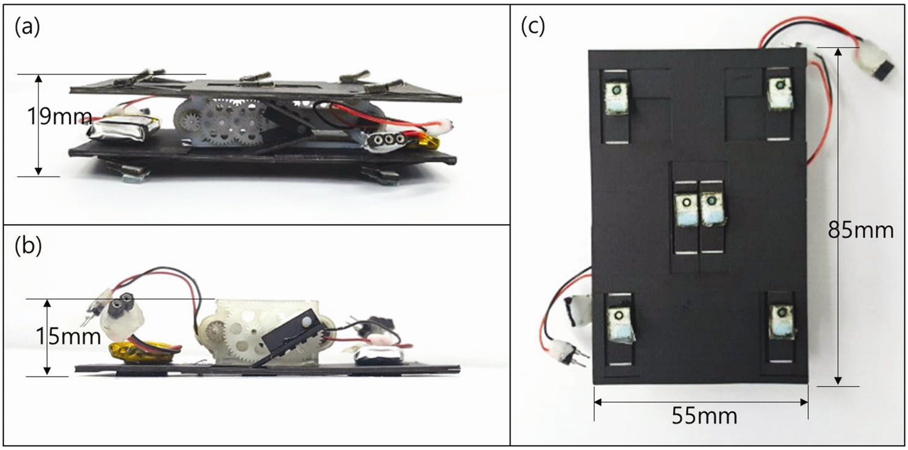

Fig. 1. Double-sided CardBot: A 26.39 g, 85 mm × 55 mm × 19 mm crawling robot. Side view (a), Single-sided CardBot (b) and top view (c).

To allow the robot to operate on either of its sides, robot bodies are attached to the top and bottom surfaces of the motor part. Double-sided traveling robots contain a motor that represent a large portion of their total height. Since a flat robot body is added, it is possible to capitalize on the advantages of a flat body shape, particularly occupied space, meaning double-sided traveling functionality only adds a height of 4 mm. Final height of the double-sided crawling robot is 19 mm.

In the following sections, design of this robot, crawling performance test, conclusion, and future work will be described.

2 Design

The robot consists of a lower body, a motor part, and an upper body. The lower body and the upper body have the same structure, which contain slider, crank, and leg links as shown in Fig. 2(a). The upper and lower cranks are connected with a single rotational joint for the purpose of simultaneous operation. As the rotating motor pushes the upper and lower slider crank to the negative x-direction, leg links are protruded. When pushed in positive x-direction, slider cranks let the leg links intrude. As a result of the protrusion and intrusion of leg links, the robot can crawl in the positive x-direction. Since the leg links are protruding in the same direction, the robot moves in the same direction from both sides.

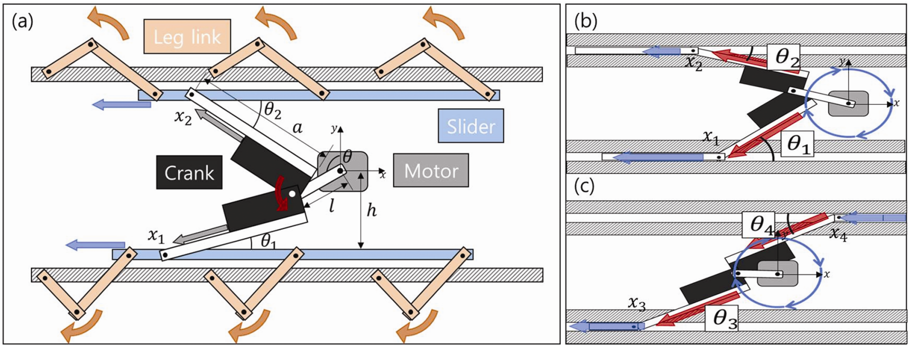

Fig. 2. Schematic view of the Double-sided CardBot (a) and friction forces of the slider crank (b), (c).

$$\theta_1 = \theta_3 = \sin^{-1}\left(\frac{h + l\cos\theta}{a}\right) \tag{1}$$

$$\theta_2 = \theta_4 = \sin^{-1}\left(\frac{h - l\cos\theta}{a}\right) \tag{2}$$

$$x_1 = x_3 = -a\cos\theta_1 - l\sin\theta \tag{3}$$

$$x_2 = -a\cos\theta_1 - l\sin\theta \tag{4}$$

$$x_4 = a\cos\theta_1 - l\sin\theta \tag{5}$$

Due to the Limited torque of the motor, the friction of slider crank has to be minimized to achieve better driving performance. Figure 3 indicates the location of the slider for the designs indicated in Fig. 2(b) and (c). Phase lag between upper and lower body is shown in both graphs. Assuming the same amount of force transmitted to the crank which is indicated as red arrow, vertical component of the force determines the magnitude of the frictional force between the slider and robot body which is indicated as blue arrow. Friction of the slider is important in the phase when leg links protrude because large torque is transmitted to the motor in this phase. Vertical force in the protraction phase in Fig. 2(b) is larger than in Fig. 2(c) when the motor rotates in clockwise. In addition, the force component in the vertical direction will temporarily deform the structure and is unable to deliver sufficient torque to the floor.

As a result, the final design was determined as Fig. 2(c). However, in this design, fatigue occurs frequently because the cranks interfere with each other more than in Fig. 2(b). For this reason, the experiment in the next chapter has been conducted with the design of Fig. 2(b).

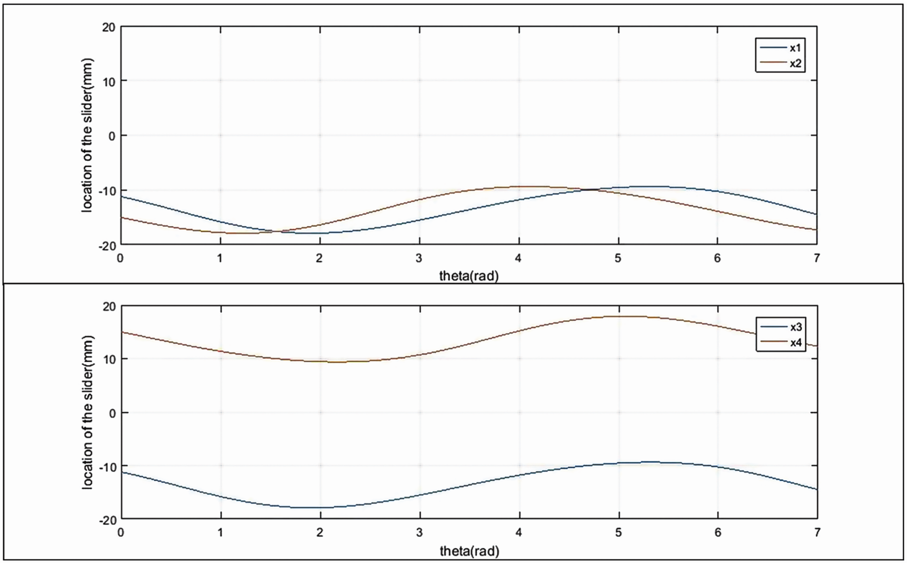

Fig. 3. Location of the upper slider and lower slider in x direction

3 Experimental Result

Running sequence of the robot was recorded using a high-speed camera(Miro eX4) at 1000 fps. Measure time for the robot traveled 0 cm, 5 cm, 10 cm, and 20 cm is 0 s, 0.20 s, 0.43 s, and 0.79 s respectively. As a result, the speed of the Double-sided CardBot is measured as 0.25 m/s. Speed of the Single-sided CardBot is also measured by high speed camera as 0.27 m/s.

4 Conclusion and Future Work

This paper presents a robot, with a height of 19 mm, and a length of 85 mm, that can travel on both sides.

This design performs at a slower speed when compared to the speed of a robot that the body attached only at one side, 0.25 m/s and 0.27 m/s respectively. As a result, this both-sided traveling robot can operate on both sides at the cost of a slight speed reduction. As mentioned previously in design section, speed reduction was caused by increased friction due to torque and increased weight of about 4 g.

In the future, this design will further change, so that the upper and lower plates may rotate with of less friction, further improving the running performance. In addition, an appropriate payload will be applied to minimize vertical movement and improve driving performance.

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