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Basic Running Test of the Cylindrical Tracked Vehicle with Sideways Mobility

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Abstract—
In this paper, the basic running performance of the cylindrical tracked vehicle with sideways mobility is presented. The crawler mechanism is of circular cross-section and has active rolling axes at the center of the circles. Conventional crawler mechanisms can support massive loads, but cannot produce sideways motion. Additionally, previous crawler edges sink undesirably on soft ground, particularly when the vehicle body is subject to a sideways tilt. The proposed design solves these drawbacks by adopting a circular cross-section crawler. A prototype. Basic motion experiments with confirm the novel properties of this mechanism: sideways motion and robustness against edge-sink.
Keywords: Tracked Vehicle, Sideways Motion, Circular Cross-Section, Crawler, Pipe Inspection

I. Introduction

Conventional crawlers cannot move sideways. Therefore they usually (i) lack enough maneuverability to move in narrow spaces such as in Fig. 1(a). For example, it is not so easy to set the position of the crawler vehicle to trajectory number 5 in Fig. 1(a). In addition, when a conventional crawler tilts sideways on soft ground, (ii) the edge of the crawler unit might sink undesirably as shown in Fig. 1(b). In this paper we present a mechanism that solves these two issues. A crawler mechanism that realizes sideling motion is presented and the application of a pipe inspection robot is examined.

In order to realize holonomic omni-directional motion, there exist many commercial wheels which are based on small passive rotational wheels[1]-[8]. Some of them are similar to a crawler-like mechanism. A particularly accomplished example of this is the VUTON[9] developed by Hirose, or the vehicle developed by M. West et al.[10] and the mechanism developed by Chen et al[11]. However, these crawler-like mechanisms have many numbers of small passive rotational rollers, and are not generally capable of overcoming steps or ground discontinuities typical in environments such as houses, offices or hospitals (e.g. the gap at an elevator opening). This limitation stems from the fact that the diameter of the passive wheel is much smaller than the diameter of the whole wheel.

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II. Tracked Vehicle with Circular Cross-Section

The overview of the proposed crawler with a circular cross-section is shown in Fig.1. The crawler module has an active rotational axis; which allows it to realize the required sideways motion.
Additionally, this configuration has another distinctive feature, shown in Fig. 2.

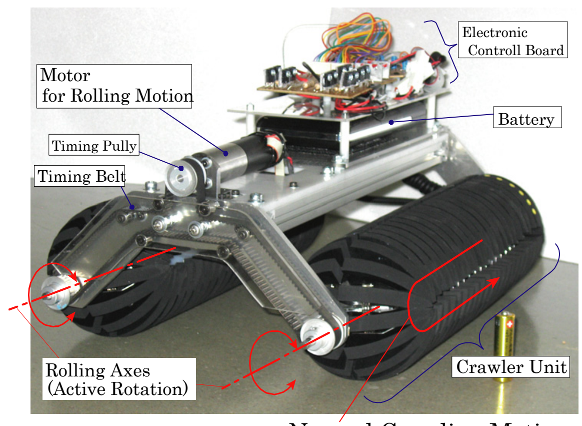


Fig. 1: Overview of the Cylindrical Tracked Vehicle

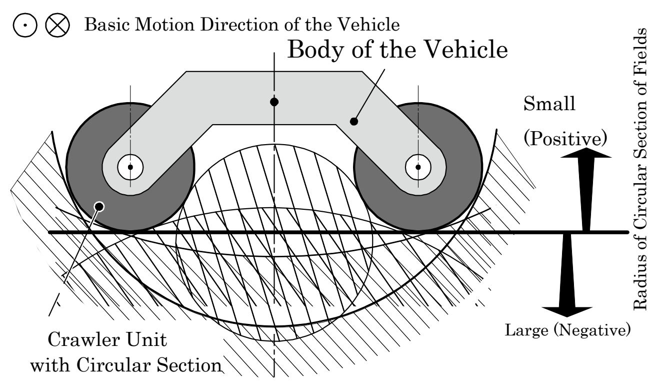


Fig. 2 Fitting by design to various pipe sizes (Front View

When a conventional crawler moves inside a pipe (or on its outer surface), the edge of the crawler belt contacts the surface with a small area: an edge line. Or conventional one should change their inclining angle in roll axis adopting to the surface of the pipe [18]. On the other hand, when the proposed crawler with a circular cross-section moves on the inside (or outside) of a pipe, the contact area is significantly increased due to the shape and elasticity of the circular crawler belt. In addition, the circular cross-section reduces the problem of the crawler unit sinking into the pipe surface. Robots mounted with the proposed mechanism move in a direction perpendicular to the passive wheel axis, as shown in Fig. 2. The maximum step which the mobile robots can overcome is significantly small relative to the size of the whole wheel because of the small diameter of the passive wheels.

III. Experiments of Basic Running

In this section, we describe a set of experiments conducted to confirm the performance of a prototype of this crawler vehicle with the omni-crawler drive mechanism.

A. Step ClimbingMotion

A-1 Forward-Backward Direction

As one of the basic mobility criteria of this robot, the ability to produce step-climbing motion should be confirmed. One example of such a motion is shown in Fig.6. The height of the step is 36mm. When the crawler vehicle needs much higher ability to climb steps, the configuration can be set the joint mechanism like connected crawler vehicle "Soryu[15]" by removing the front supporter.

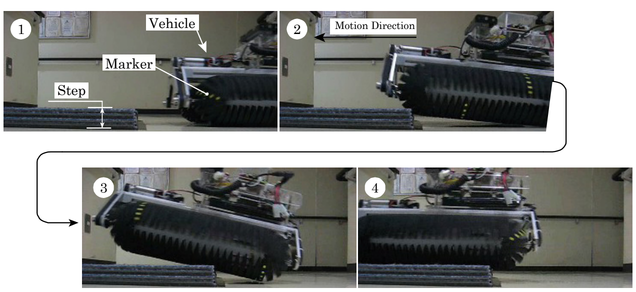


Fig.3: Step-Climbing Motion (Forward-Backward)

A-2 Sideways

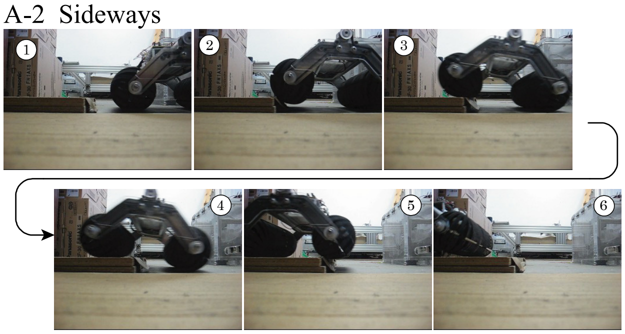


Fig.4: Step-Climbing Motion (Sideways)

The height of the step is 33.5mm in Fig.4. It was observed that a prototype with the Omni-Crawler mechanism can climb step not only longitudinally, but also laterally.

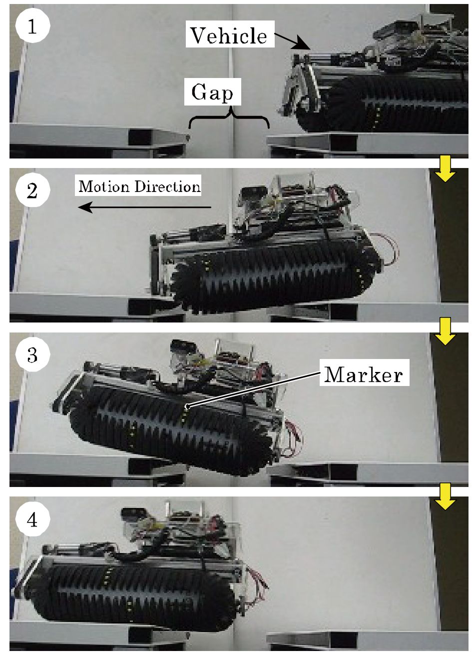


Fig.5: Gap-Traversing Motion (Forward-Backward)

B. Gap Traversing

The ability of the vehicle to gap traversing was also confirmed as shown in Fig.8. The distance of the gap is 205mm. It was observed that a prototype with the Omni-Track mechanism can traverse the gaps only longitudinally, but also laterally as shown in Fig.8 and Fig.9 respectively. In Fig. 9, the length of the gap is 77.5mm.

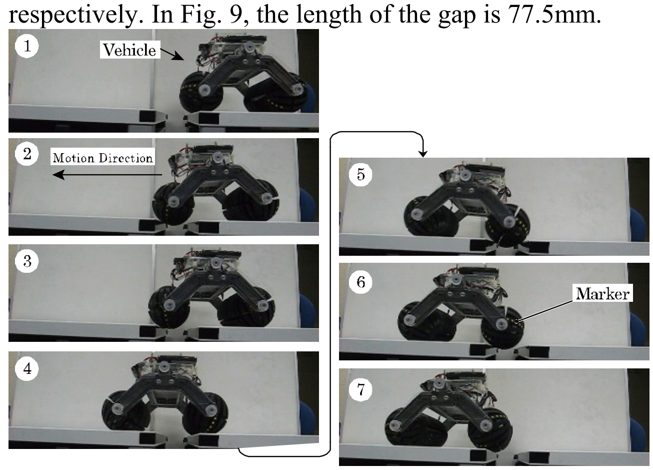


Fig.6: Gap-Traversing Motion (Sideways)

In order to compare the ability of the step climbing and that of gap traversing in sideways, it is set the diameter of the roller of the previous tracked mechanism is half size of that of the Omni-Tracked mechanism as shown in Fig. 7. By defined like this, the ability to climb the step and gap is as shown in Fig. 8. As shown in this graph, each ability of the Omni-Tracked mechanism is higher than that of the previous model defined here.

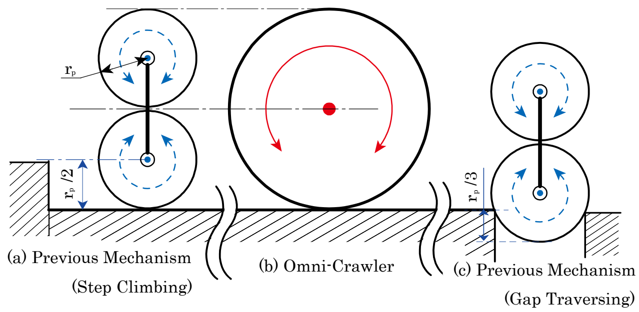


Fig.7: Comparison of the Diameter of Roller with Diameter of Omni-Crawler (Front View)

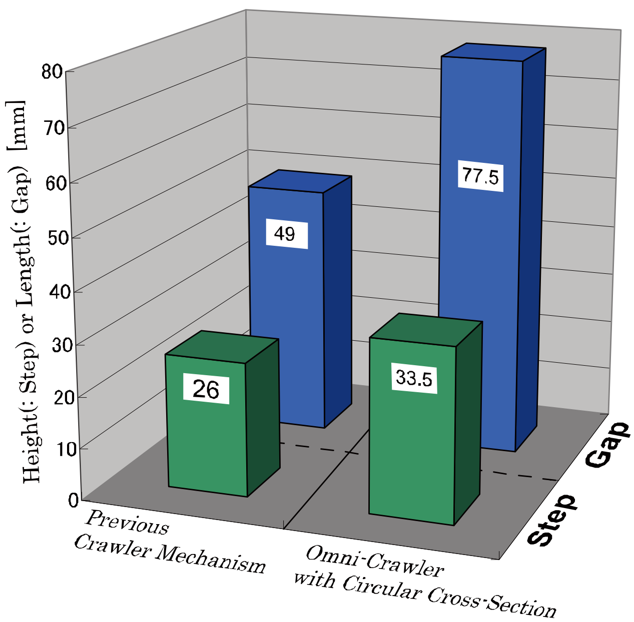


Fig.8: Comparison of Capability with Previous Crawler with Omnidirectional Mobility

C. Moving on Pipe

(c-1) Geometric Conditions

The vehicle's mobility on the outside edge of a pipe was also confirmed. It was observed that the prototype with the Omni-Crawler mechanism can traverse along small and large pipes without any adjustments as show in Fig.17. Similarly, motion along the inside of a pipe was also observed, and it was confirmed the vehicle could maintain smooth motion without requiring any kind of adjustment. See Fig.18. The diameter of the outer pipe is 513mm and inner diameter of the pipe is 490mm.

$$W/2 - r_{oc} < R_p \leq \infty \quad (1)$$

$$r_{oc} + W/2 < R_p \leq \infty \quad (2)$$

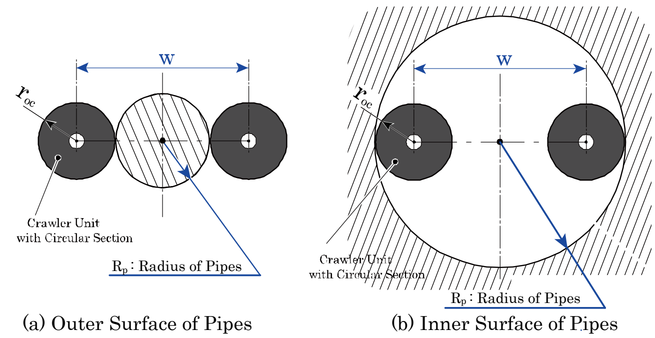


Fig.9: Geometric Conditions

Please see the video attached this paper.

In addition, the stability of the cylindrical tracked vehicle is considered with the comparison with that of previous crawler as shown in Fig. 10.

As a result, the cylindrical tracked vehicle has higher stability than normal tracked vehicle.

(c-2) Moving on the surface of the pipes

The ability to move on the outside surface of the pipes was confirmed. The vehicle can keep moving even if the diameter of the pipe-like field changed as shown in Fig. 11. The diameter of the small pipe is 155mm, while that of the large pipe is 513mm. They meet the values based on the equations shown in the previous section.

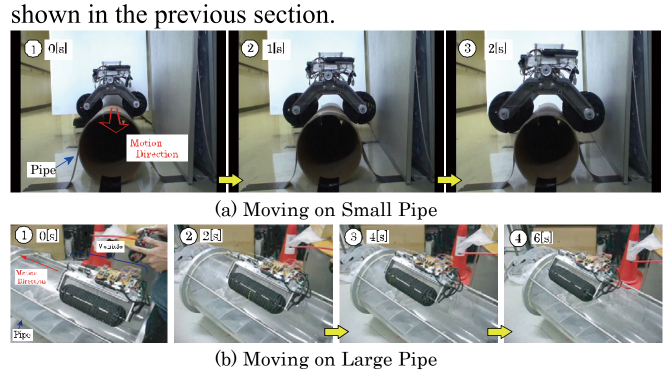
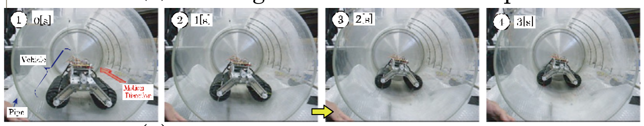


Fig.10: Moving on the Surface of the Pipes

(c-3) Moving on the surface inside the pipes

The ability to move on the surface inside the pipes was also confirmed. The vehicle can keep moving even if the diameter of the pipe like field changed. For example from pipe like field to the totally flat area, the diameter is shift from the one to the infinity, the prototype model can move through that connection point as shown in Fig. 11. The diameter of the small pipe is 349mm, while that of the large pipe is 490mm. They meet the values based on the equations shown in the previous section. Even if there is an obstacle inside the pipe, this tracked vehicle can avoid that by making use of the sideways motion within the stable range.

(a) Moving inside the Small Pipe



(b) Moving inside the Large Pipe

Fig.11: Moving Inside of the Pipes

D. Moving on Soft Grounds

(D-1) Toyoura-Sand

The vehicle's ability to move on soft ground was also confirmed, as shown in Fig. 15. We used "Toyoura" sand as the soft ground. The average diameter of this sand particle is about 0.2mm, and the density of this sand is 2700kg/m3. It was observed that this prototype with the Omni-Crawler mechanism can move on soft ground smoothly with a low level of sink. Please see the video attached this paper.

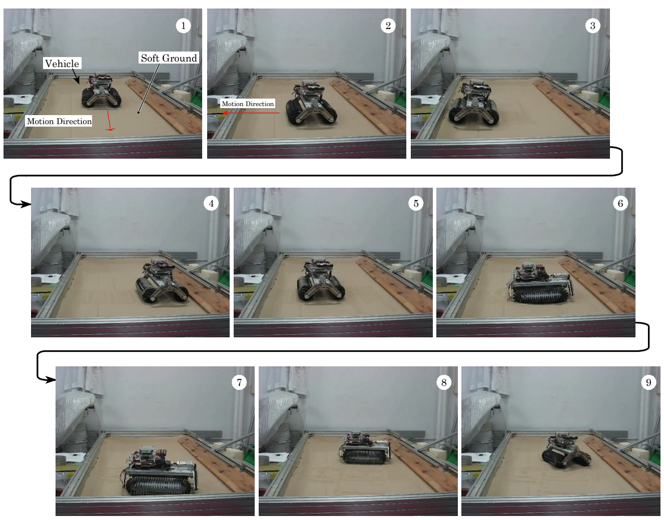


Fig.12: Moving on the Field with Toyoura-Sand

In order to see the effect of prevention of sinking on the inclining posture as explained in Fig. 1, the running experiment on the sand with step is observed as shown in Fig. 13. One of the tracked unit is on the step and the height of the step is 115mm. The rut of the cylindrical track is shown in Fig. 14(a). On the other hand, the rut of the normal track is shown in Fig. 14(b). The height and the width of the normal tracked vehicle were set the same size of the diameter of the cylindrical tracked vehicle. The weight of each tracked vehicle was set the same.

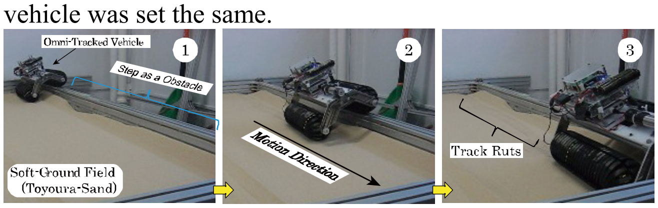
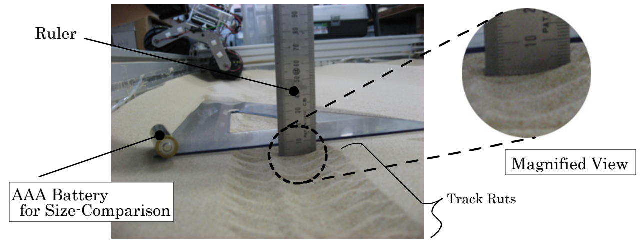
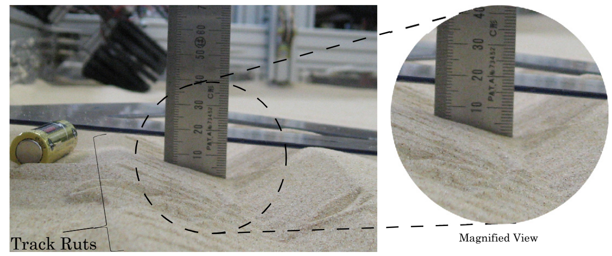


Fig.13: Moving with Inclining Posture



(a). Track Ruts on the Sand by the Omni-Crawler



(b). Track Ruts on the Sand by the Normal Track

Fig.14: Comparison of the Track Ruts on the Sand

The depth of the rut of the cylindrical track is the 8.5mm, while that of the normal track is the 15.5. It was observed that the cylindrical tracked vehicle has better performance of the prevention of the edge sinking on the inclining posture in soft ground.

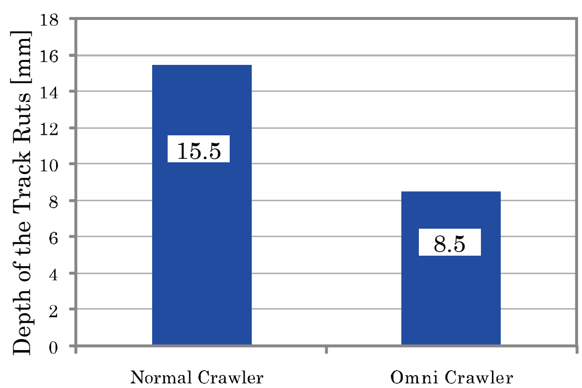


Fig.15: Comparison of the Depth of the Track Ruts

Fig.16: Infiltration of Sand into the Conventional Tracked Belt

In addition, as shown in Fig. 16, when the tracked vehicle with conventional crawler belt was rotating on the spot, it happened that the sand infiltrated into side of the crawler belt. Comparing this conventional crawler belt, the belt of the Omni-Crawler protects the infiltration of sand from the side when the vehicle is rotating of the spot. This is another advantages of the proposed crawler mechanism with circular cross-section.

(D-2) Moving on Snow
The vehicle's ability to move on another soft ground was also confirmed. We have done outdoor running test of this vehicle on the snow as shown in Fig. 16. The thickness of the snow was about 35mm. It was observed that this prototype with the Omni-Tracked mechanism can move on soft ground smoothly not only in forward-backward direction, but also sideways, turn on the spot with a low level of a sink. Please see the video attached this paper. The water proofing is still one of the problems for the mechanism but we can see from even if the vehicle gets stuck, it can recover by using the sideways motion from the hole on the soft ground.

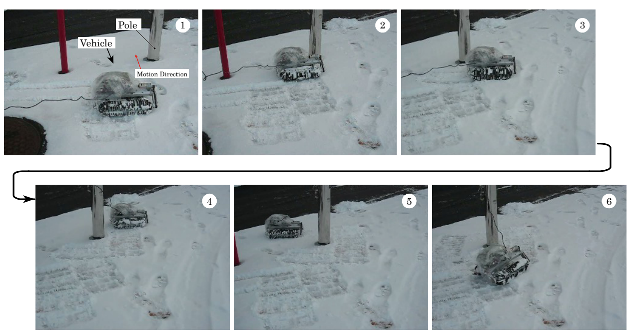


Fig.16: Basic Running Test on Snow

IV. Another Applications

In this section, another applications of the cylindrical tracked unit are shown.

4-1. Wheel–Tracked Legged Mobile Robot

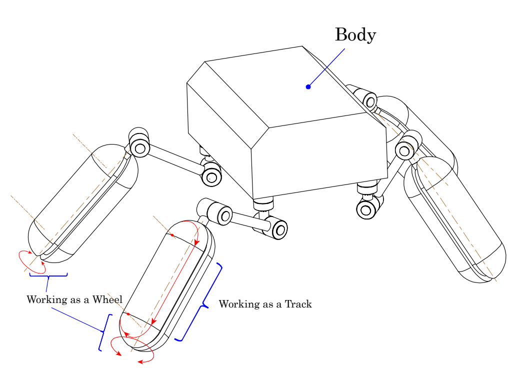


Fig.17: Concept of Wheel–Tracked Legged Mobile Robot

The wheel-track-leg hybrid mobile robot is shown in Fig. 17. This robot changes its mobile mode depends on the fields to realize the effective and efficient movement.

4-2. Pipe Inspection Robot in Vertical Pipes
The robot to inspect the inner or outer pipe which set vertical is shown in Fig. 18. It can grasp the pipes by using 3-crawler units and climb the pipes.

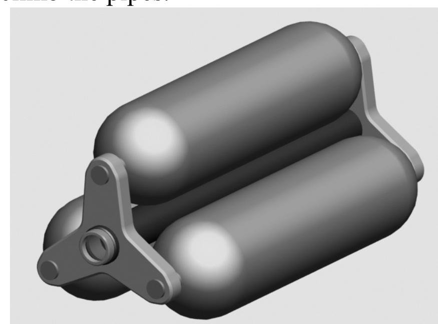


Fig.18: Concept of 3 units for pipe inspection with Omni-Track Mechanism

4-3. Snake like Robot

As shown in Fig. 19, by connecting plural numbers of the omni-crawler units, the snake-like robot(e.g. [19]) with the sideways mobility can be realized. This configuration is effective to move sideways in narrow spaces.

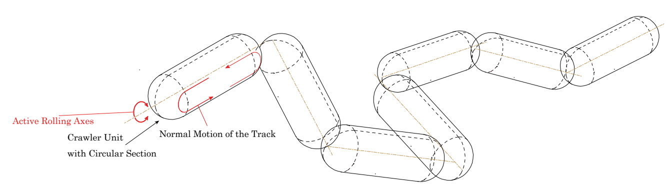


Fig.19: Concept of 3 units for pipe inspection with Omni-Track Mechanism

V. Conclusion

In this paper, we showed the basic running experiments of Cylindrical Tracked Vehicle with Sideways Mobility. The step climbing motion in forward-backward direction and also sideways are shown and compared with the previous tracked mechanism with conventional crawler belt. The motion test on the softground and snow were also conducted with the omni-tracked vehicle.

In future works, we plan to optimize the configuration of the body of the tracked vehicle including the suspension mechanism.

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