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Mechanical Design of Cylindrical Track for Sideways Motion

Kenjiro Tadakuma[1], Riichiro Tadakuma[2], Hiroaki Kinoshita[3], Keiji Nagatani[3],

Kazuya Yoshida[3], Martin Udengaard[4], Karl Iagnemma[4]

Abstract—

In this paper, a novel crawler mechanism for sideways motion 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 has been developed to illustrate the concept. Motion experiments confirm the novel properties of this mechanism: sideways motion and robustness against edge-sink. Motion experiments, with a test vehicle are also presented.

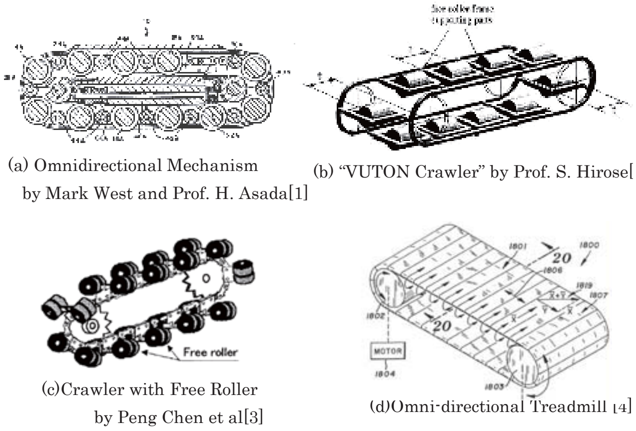
Keywords: Crawler, Sideways Motion, Circular Cross-Section, Mechanical Design, Pipe Inspection

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.

A. The weak point of crawlers which realize the sideways mobility

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.



(a) Omnidirectional Mechanism by Mark West and Prof. H. Asada[1]
(b) "VUTON Crawler" by Prof. S. Hirose[
(c)Crawler with Free Roller by Peng Chen et al[3]
(d)Omni-directional Treadmill [4]

Fig. 1: Weak points of Conventional Crawler Mechanism

II. BASIC CONCEPT OF THE CRAWLER WITH CIRCULAR CROSS-SECTION

The basic concept of the proposed crawler with a circular cross-section is shown in Fig.2. 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. 3.

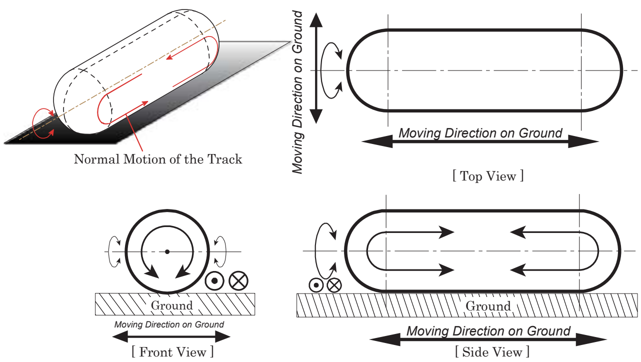


Fig. 2: Basic Schema of Omni-Crawler with Circular Cross-Section

1. The University of Electro Communications, tadakuma@gmail.com , 1-5-1 Chofugaoka, Chofu-shi, Tokyo, 182-8585 JAPAN, 2. AIST, 3.TohokuUniversity, 4.Massachusetts Institute of Technology

III. BASIC CONFIGURATION OF THE CRAWLER WITH CIRCULAR CROSS-SECTION

In this section, the basic configuration of the proposed cylindrical crawler mechanism is described. First, the theoretical cylindrical crawler is explained and after that , the mechanism of the Omni-Ball[12][13] which authors developed before (which inspired the cylindrical crawler design) is explained.

[The crawler mechanism for Omnidirectional motion]

The theoretical configuration of the cylindrical crawler is shown in Fig. 4. The motion direction is from inner of the crawler to outer. This crawler has the circular cross-section. Therefore, if there is an active rotational axis at the center of the cross section, it can move in sideways. In order to realize this theoretical configuration, one of the example of the crawler mechanism is shown in Fig. 5,6,8.

There are mainly three different crawler mechanisms to realize the omnidirectional motion as shown in Fig. 5,6,8.

(a) Multiple small crawler units

The mechanism has multiple numbers of crawler units in all directions (in a radial pattern) like the spokes of the wheel as shown in Fig. 5.

This mechanism does not need to change its crawling motion.

(b) 2-Cross shaped crawler units

Two cross shaped crawler mechanism is as shown in Fig. 6. In this mechanism, it is difficult to support the crawler to the body.

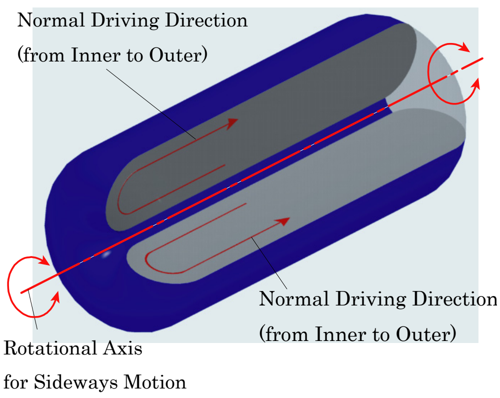


Fig.4: Theoretical Configuration of Cylindrical Crawler

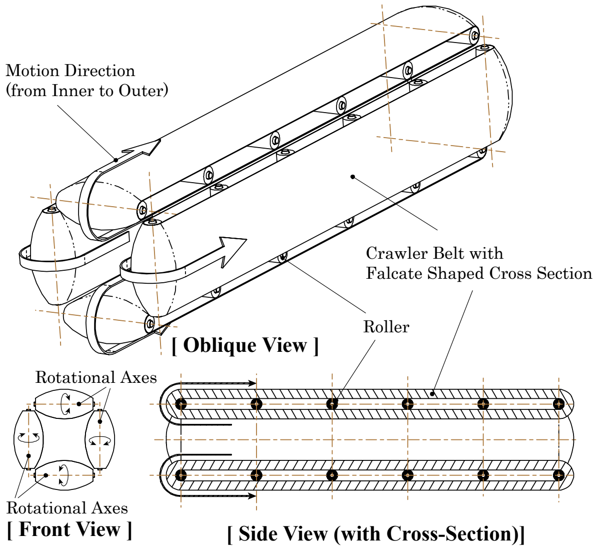


Fig.5: Configuration Type A: Multiple small crawler units

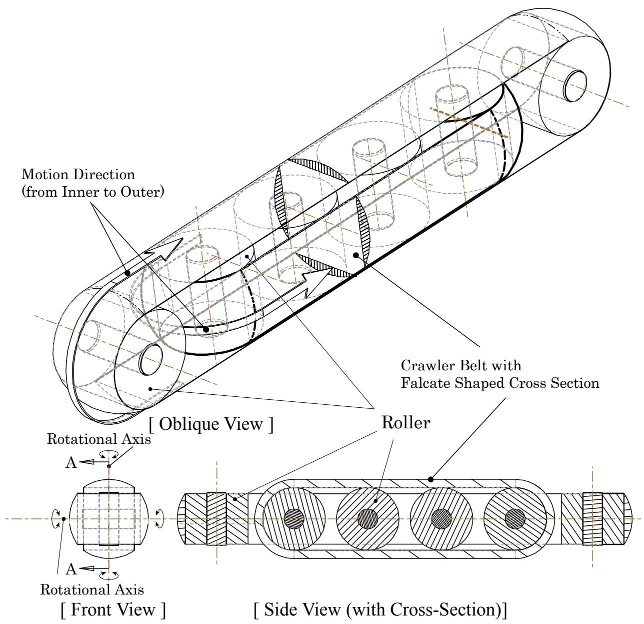


Fig.6: Configuration Type B: 2-Cross shaped crawler units

(c) Omni-Crawler: The mechanisms inspired by the "Omni-Ball"

Before explaining the configuration of the Omni-Crawler, the mechanism of the Omni-Ball is explained as follows.

(C-1). Basic Configuration of "Omni-Ball"

The basic 3D-concept model is shown in Fig.7. In Fig. 7, two hemispheres rotate passively, and the active rotational axis lies in the center of the Omni-Ball. In order to rotate, both the hemispheres are passive. Note that each passive rotational

axis is independent, so that each rotation of a hemispheric wheel is also independent.

When the active axis rotates, the Omni-Ball produces a propelling force in a direction perpendicular to the active rotational axis, as shown in Fig.7. At the same time, the wheel does not produce a propelling force in the horizontal direction in Fig.7, so that this mechanism can similarly move in an arbitrary direction by a combination of three propelling forces.

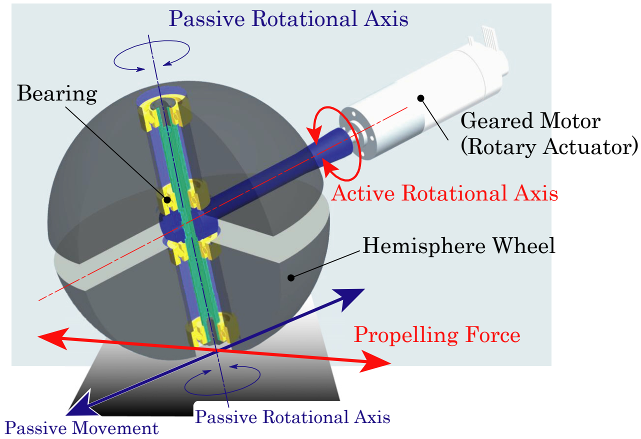


Fig.7: Basic Structure of the "Omni-Ball"

C-2. Basic Configuration of "Omni-Crawler"

The comparison between the Omni-Ball and Omni-Crawler designs is shown in Fig.8.

The Omni-Crawler is a an extension of the Omni-wheel from a sphere to a cylinder with spherical ends. From a front view, as in Fig 8[a-1] and 8[b-1], the two mechanisms are identical. The difference is evident, however, from the bottom view, as in Fig 8[a-2] and 8[b-2], where there is a cylindrical section inserted between the spherical ends of the Omni-crawler. While the surface of the Omni-ball consisted of two solid hemispheres, the surface of the Omni-crawler is composed of a belt that runs over both the cylinder and spherical ends. The belt is described in the next section.

As stated in the previous section, the hemispherical wheel of the Omni-Ball is rotated passively in Fig.8. The Omni-Crawler, however, can produce propelling force not only laterally, but also longitudinally. If a rotary actuator is mounted on the hemispherical wheel of the Omni-Ball, its longitudinal velocity must be adjusted according to the angle formed by the axis of the hemispherical wheel to the ground, because the relative radius of the wheel will change based on the inclining angle of the wheel mechanism. Fig.8(b) shows a schema of the Omni-Crawler: the crawler mechanism to realize sideways motion. Note that in contrast with the omni-ball, the velocity of the crawler in forward direction is independent of the inclining angle of the driving unit, as shown in Fig. 8[b-1] and [b-2].

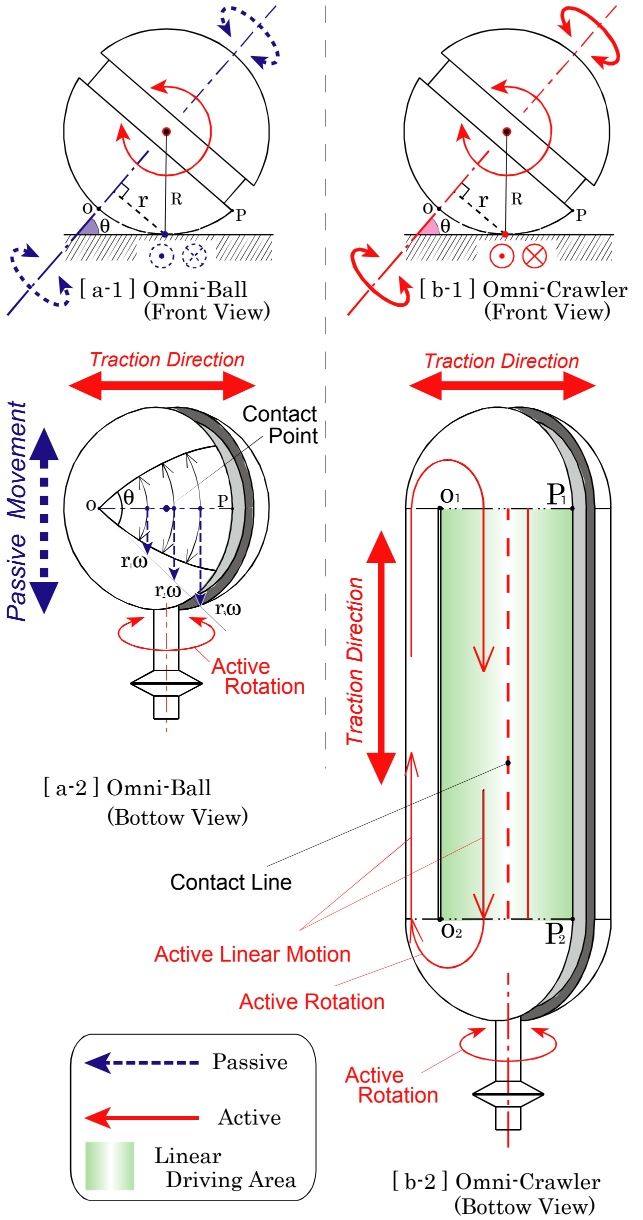


Fig.8: Basic Principle of the "Omni-Crawler"

The velocity of the vehicle with Omni-Ball is described by,

$$Vob = R\,\{\cos(\pi/2)-\theta\}*\omega$$
$$=(R * \sin\theta) *\omega \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

and it is dependent on the incline angle of the Omni-Ball. On the other hand, the velocity of Omni-Crawler "Voc" is as follows (linear contact with ground hypothesis)

$$Voc= R* \omega\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

This is the basic principle of the Omni-Crawler. Summarizing:

(i) There is a singularity line on the Omni-crawler that does not allow any longitudinal traction force to be generated.

(ii) The system can move omni-directionally (by combining the rolling motion in roll axis).

(iii) The system can move longitudinally by standard motion of the track.

(iv) It can adjust its velocity in any arbitrary direction.

IV. Mechanical Design of the Crawler with Circular Cross-Section

The drawing of the inner mechanism of the Omni-Crawler is shown in Fig. 10. There are mainly 5 kinds of part in this mechanism: Driving Unit, Supporting Unit, Main Body, Tensioner, Rolling Shaft. In the driving unit, there is a geared motor, coupling, bevel gear set and so on as shown in Fig.9.

1) Driving Unit

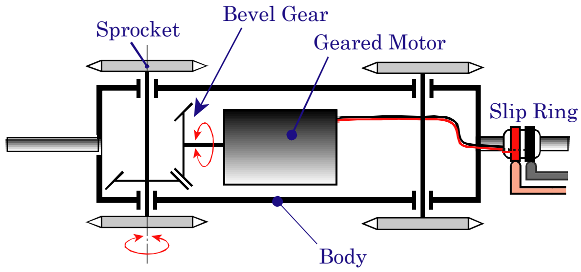
The procedure of the rotational transmission from the motor to the sprockets is as follows. The geared motor transmits the rotational motion through the coupling to the bevel gear set and the rotational direction is changed from in rolling axis to pitching axis, and finally the sprockets are rotated. (To change the direction of the rotational direction from in rolling axis to pitching axis, as a driving transmission, an worm gear set can be used, but this time, for the omni-crawler, the center of gravity of the inner mechanism should be almost the center of the cross section of the mechanism, and if the worm gear is used, the position of the motor should be offset from the center of the cross section, and it can cause the offset of the center of gravity, because the geared motor has normally larger relative density as component than other parts like a Al flame, screw and so on). Even if the spur gear is used for set the position of the motor and final rotational axis in the pitching axis at the center of the cross section, however, the space and simplicity of the mechanism, the bevel gear set was adopted as a first model.

The distance between right and left sprockets should be small enough to realize the circular cross-section. Therefore, the driving mechanism should be set into this narrow space. In order to set the position of the large bevel gear into the box A: narrower than the distance of the two sprockets, the boss of the bevel gear is put the reverse side compared with the normal side by using the short cylindrical shaped part. This cylindrical part and the large bevel gear are connected with pins and fixed each other. Even if we put a spur gear or timing pulley in this box, there should be a bevel gear module to change the direction of the torque from the geared motor, and the position of the bevel gear module should be between the sprocket unit and geared motor by necessity.

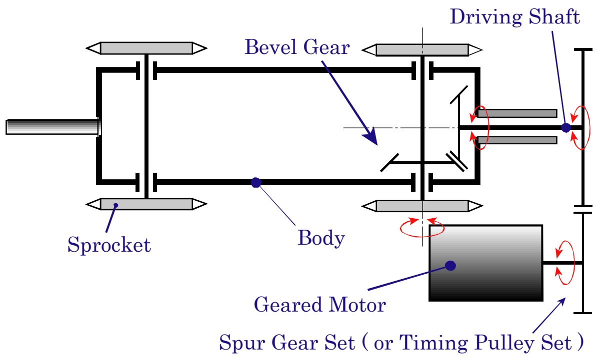
If the direction of the shaft of the geared motor is on the pitching or yawing axis of the module, there is no need to change the direction of the rolling motion(: torque) of the geared motor, eventually there is no need to put a bevel gear units. However, the length of the electronic geared motor as product is generally longer than that of the diameter (in its axis along to its own shaft), so that if the direction of the geared motor is set as mentioned above, the whole size of the Crawler unit, especially, the radius of the cylindrical crawler lug should be larger to includes the geared motor inside the space.

It is possible to put the motor not in the inner module but at the outside of the module as shown in Fig. 9 (b). The sprocket is rotated by the rotational motion of the bevel gear through the driving shaft. However, in this configuration, the driving shaft should be rotated sync when the whole module is rotated for the sideways motion.

Finally, as the first prototype model, the configuration of the bevel gear unit type, and the configuration (a) in Fig. 9 was adopted.



(a) Geared Motor in Module



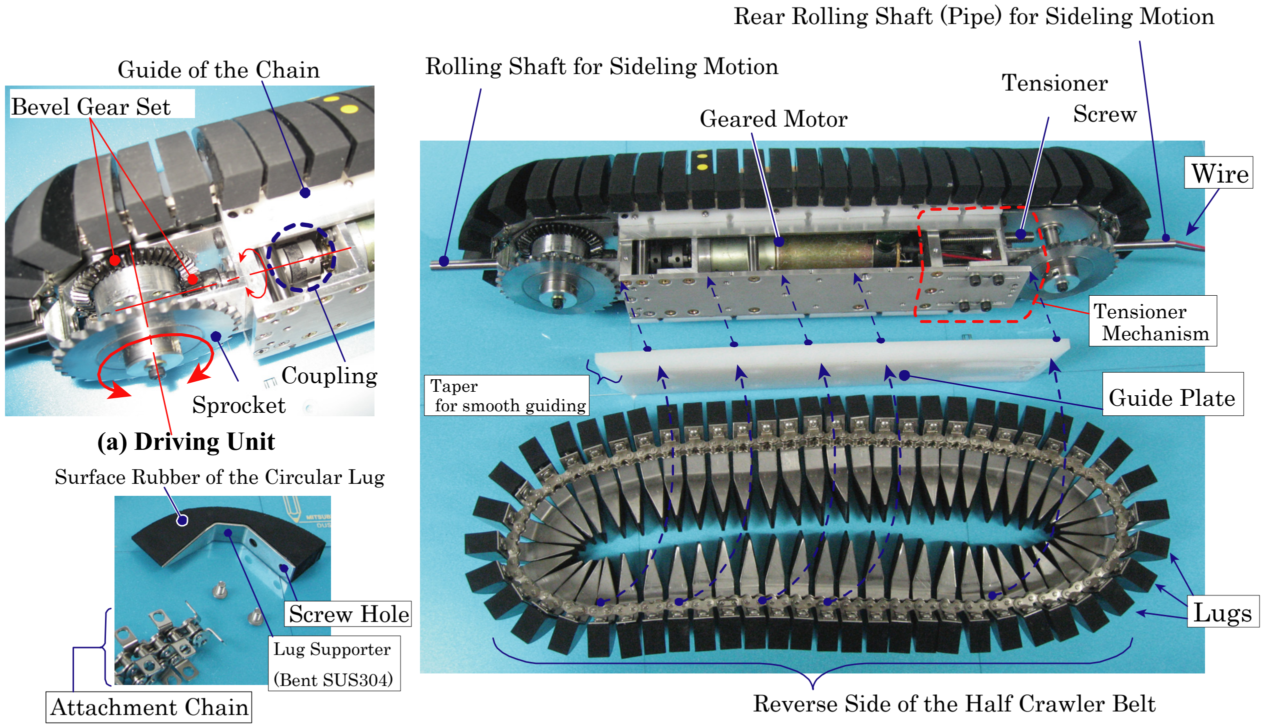
(b) Driving Shaft in Module (Motor is out of module)

Fig.9: 2 Types of Configurations of the Inner Module(Top View, cross-section)

2) Supporting Unit

There are mainly two kinds of supporter here in the inner mechanism of the Omni-Crawler. One is the supporter for the attachment chain, the other is the supporter for the lugs: Guide Plate, especially when the inclining angle of the Omni-Crawler is over 45 degrees. The material of the supporter is “Ultra high molecular weight polyethylene”. This material has normally smooth and smaller friction than Tefron. The supporter for the chain also works as guide of the chain by using the convex shape as shown in Fig.9. The supporter for the lugs has the taper shape at the end of itself to smooth guiding for lugs. The other way to support the chain and lugs is to use free rotational roller. This way can be smaller friction than board. However, on the other hand, the mechanism is apt to bulky and high cost to be made, so that, finally the supporter consists of just one board was adopted as

the first final model this time.



(a) Driving Unit

(b) Circular Lug of the Crawler Belt **(c) Half-Deployed View of the Crawler Unit**

Fig.10:Configuration of the Omni-Crawler

3) Main Body

The main body has box configuration as shown in Fig.10. In order to replace the geared motor easily when it is broken, the supporting shaft H2, H3 is fixed on the other hand, the shaft H1, L1-3 are fixed to the side plate not only the tighten screw but also the .It means, there are “L shaped” supporting configuration.

Therefore, when the H2 and H3 are removed in order to access the geared motor, even there are no H2, and H3 as

supporter, there still remains enough strength in the configuration of the body by L shaped support.

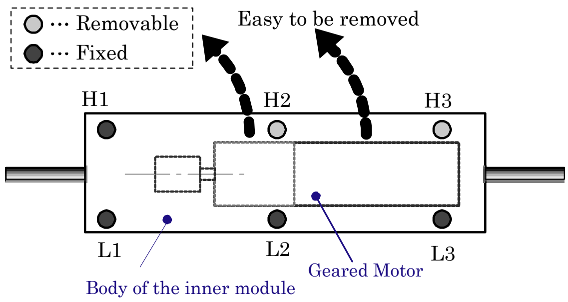


Fig.11: Ease of maintenance of inner module(Side View)

4) Tensioner

For crawler belt, the tensioner which adjusts the distance between the axis of the front sprocket and rear sprocket is needed. Some normal tensioners for previous normal crawler are developed by some other groups e.g. [9][19].

Normally, the normal tensioner is outside of the crawler belt or the mechanism to change the direction of the movement of the screw into the vertical direction. The Omni-Crawler has the slit in the crawler belt,

therefore there is the access space for the tool like L wrench. As a result, the tensioner for the Omni-Crawler has been designed as shown in Fig.10.

5) Rolling Shaft

The material of the rolling shaft is SUS304 with has enough strength. And rear rolling shaft has inner hole for wire of the motor.

There is needed slip ring at the rolling shaft or inner radio transmission or driving .On the way C, when the crawler mechanism is rotated in its roll axis and the inner axis does not rotate to body of the vehicle, relatively the inner axis rotates to the body of the inner mechanism and the normal crawling motion is occurred as a result. In order to prevent the

This is the similar phenomenon in the steering mechanism for omnidirectional vehicles.

In order to the control method simpler and the lower position of C.O.G., the configuration is adopted as a first prototype model this time.

[Belt]

The belt of Omni-Crawler is consist of an attachment chain and quarter circular shaped lug.

1) Attachment Chain

2) Shape of Lug

The pitch of the attachement chain is fixed. For example, as product, there is just only 6.35 mm pitch chain. This time, attachement chain should be inside of the circle composed by

lugs by necessity.

To make the smooth rotation at the each end side of the cylindrical crawler, the larger number of the lugs is better and the connected point to the attachment of the chain is better to be large. This is the reason why the diameter of the sprocket, larger is better.

And the angle α of the lugs as shown in Fig.12 can be set from the connected point of the lug and attachment of the chain and the pitch of the crawler. The angle should satisfy the following equation. The diameter of the sprocket "D" can be decided from that condition as follows.

$$2 \text{ pitches} = l = (D/2) * \alpha \quad \text{..........................(3)}$$

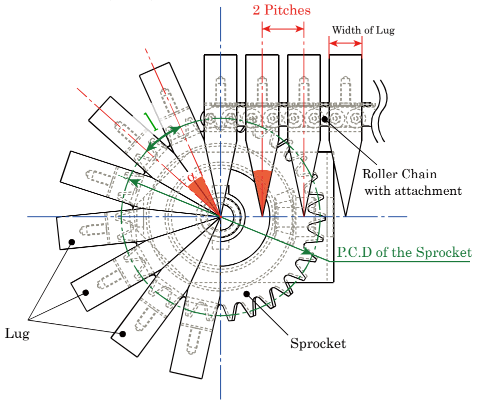


Fig.12: Geometrical Condition of the Shape of Lug

Note that the width of the crawler unit "Wc"and height "Hc"and diameter of the crawler unit "Dc"are satisfied the following equation(4) and as shown in Fig.9 and table 1, the actual model satisfy these relations.

$$Wc = Hc = Dc \quad \text{..........................(4)}$$

Table.1 Specification of One "Omni-Crawler"

Length	359 mm
Distance between two sprocket axes	255 mm
Width	104 mm
Height	104 mm
Diameter of the section circule	104 mm
Weight	3.05 kg
Material of the lug surface	Nitrile Rubber
Material of the lug supporter	SUS304
Pitch of the lug	12.7 mm
Motor	90W (NIPPO MM-26E) x2

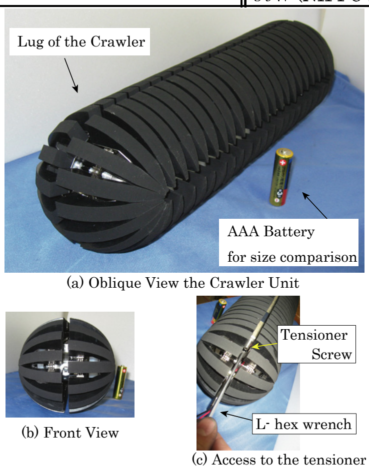


Fig.13: Actual Prototype Model of "Omni-Crawler" Unit

V. Basic Experiment of the Crawler Unit

In this section, we describe a basic experiment conducted to confirm the performance of a prototype of this crawler Unit with the ability of a sideways motion.

As one of the basic mobility criteria of this unit, the ability to produce forward and sideways motion should be confirmed.

The basic experimental device is shown in Fig. 14 as follows. This device is consist of the casters, flame to support the omni-track unit and the geared motor to put the rotational force at the center of the crawler unit in cross-section in order to realize a sideways motion finally.

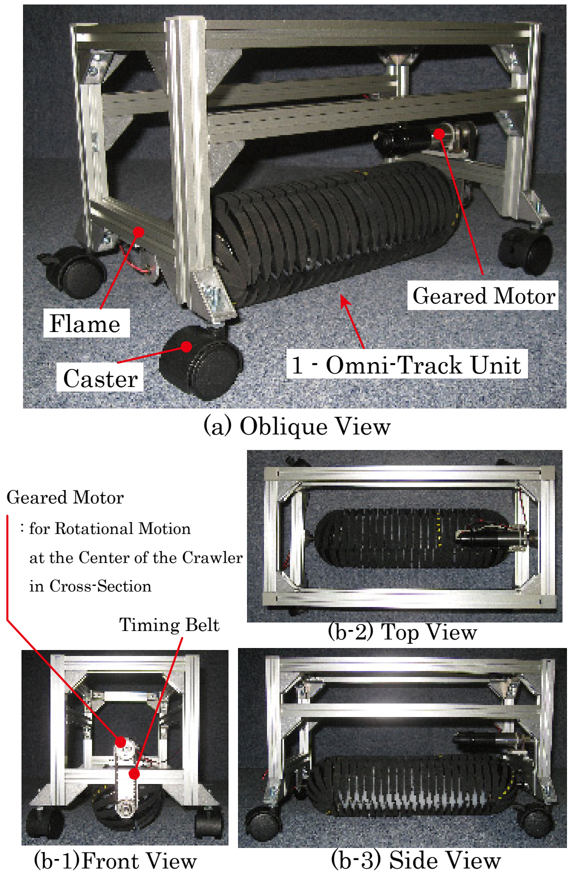


Fig.14: Basic Experimental Device

The height of the device is 254mm, the length is 415mm, the width is 200mm, and the weight of the device is about 5.92kg.

One example of forward and sideways motion is shown in Fig.15. The crawler unit in the experimental device is radio-controlled by the operator with the manual controller through microcomputer H8. The 12V battery is also mounted.

The basic running experiment was conducted in the filed with the grid line to show motion of the crawler unit well. The casters of the device disturbed the motion some times, but basically it was observed that this prototype model has the ability to move in a forward and sideway directions smoothly as shown in Fig. 15.

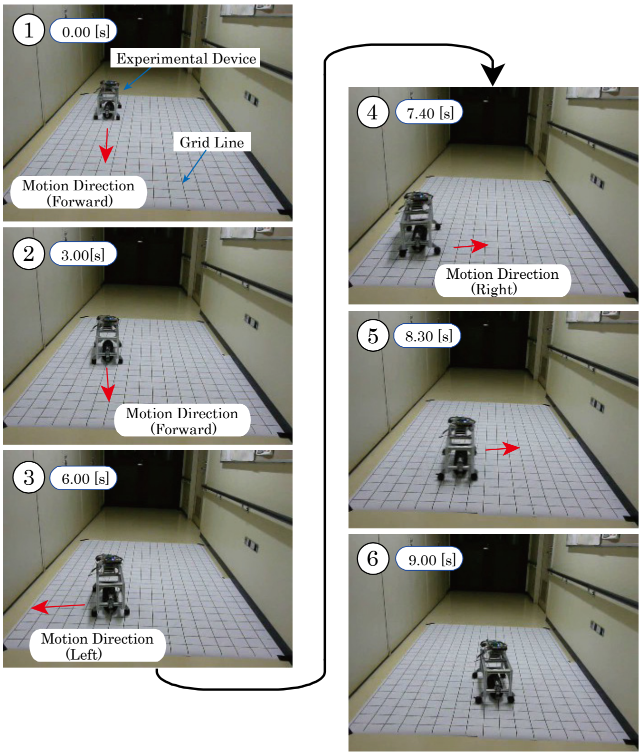


Fig.15: Forward and Sideways Motion on Floor

V. Conclusion

In this paper, we showed a new crawler unit mechanism inspired by the "Omni-Ball" that has a circular cross-section and can realize sideling motion. The details of the design of this unit are showed and discussed. We confirmed the basic performance of the crawler unit mechanism through a basic experiment.

In future works, we plan to put the two omni-track units and compose the vehicle with sideways motion. In addition, some running experiments in several fields such on a snow or sand and so on will be conducted.

Acknowledgment

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