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Flexible Mono-tread Mobile Track (FMT) - A New Mobile Mechanism Using One Track and Vertebral Structure -

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1. Introduction

Lots of disaster such as huge earthquakes, the 1995 Kobe earthquake in Japan (as shown in Fig.1), followed by the 2004 Indian Ocean earthquake and the 2008 Sichuan earthquake and so on, in addition, 11th September 2001 attack on the World Trade Center, have led us to recognize the necessity to utilize robots in search and rescue at disaster areas.

Fig. 1. Collapsed Japanese wooden houses in Kobe (1995, the left figure) and Noto (2007, the right figure) earthquakes

Research and development activities for the utilization of robot technology to assist humans in rescue operations have resulted in a challenging field of robotics: Rescue Robotics. The rescue robots must function in extremely hazardous and very complex disaster environments, moreover, the composition of rubble in the disaster area varies due to regional circumstances and types of disasters, etc. Hence, it is very important to develop mobile mechanisms that enable robots to travel across such the rubble and access to the interior of the rubble pile. The importance of development of powerful mobile mechanisms has been also indicated in ``the special project for earthquake disaster mitigation in urban areas'' by The Ministry of the Education, Culture, Sports, Science and Technology in Japan (DDT-report, 2006). Then, serpentine robots (Takayama & Hirose, 2003, Arai et al., 2004 & 2008, Osuka & Kitajima, 2003, Kamegawa & Matsuno, 2007, Miyanaka et al., 2007) have been developed as search robots to travel across the rubble of collapsed buildings for the purpose of finding victims trapped in the rubble with expectation of powerful tools for the purpose. They have surely high mobility. However, as indicated in (Miyanaka et al., 2007) these robots have such problems as follows: if the bottom sides of the robots, which are not covered by tracks, get on an edge of obstacles, the robots become hung in the air. See the left figure of Fig.2. And if the connecting joint parts (The serpentine robots usually consists of some segments which are connected by joints) get on an edge of obstacles, the robots get stuck. See the right figure of Fig.2.

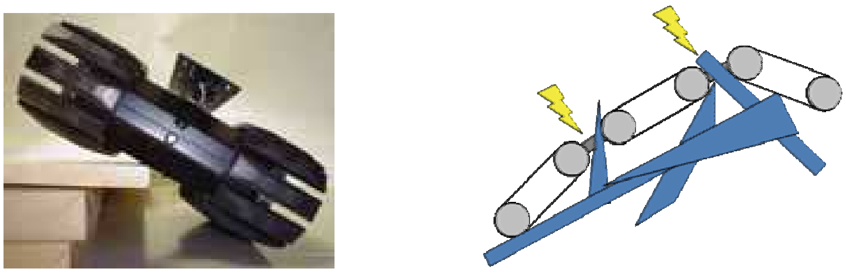


Fig. 2. Stuck situation of track vehicles. The left figure indicates that a track vehicle becomes hung in the air. The right figure shows that connecting joint parts get on an edge

Hence, in this chapter, to get over the problems, we propose a new mobile mechanism: Flexible Mono-tread Mobile Track (FMT). FMT has only *one* track which wraps around the vehicle body, and the body flexes in three dimensions when the vehicle turns, climbs up and down stairs, and so on (see the left and right figures of Fig.3).

Fig. 3. Flexible mono-tread mobile track (FMT). The left and the right figures indicate retro-flexion and lateral flexion postures of FMT.

2. Track Vehicle

Though the search robots would need various functions, among them, travelling across rough terrain such as the rubble of collapsed buildings would be one of the most important. Tracks are known as very effective for vehicles to travel on extremely rough terrain. And the mobility of the vehicles using tracks would be higher as the overall length of the tracks gets longer. Hence, for getting longer tracks, serpentine robots have the same structure in common; the robots consist of several segments each of which has tracks and they are connected by joints. However as indicated in previous section, these robots have such problems as described above. In addition, this architecture would need more actuating mechanisms as the number of joints increase, then problems would also arise that increase of overall weight, more complicated control system, less reliability. Then in this section we consider the conventional mobile mechanisms with tracks and make clear the problems of them.

2.1 Differential Tracks

This type of mobile mechanism employs a pair of tracks as shown in Fig.4. It is typical type, and adopted in tanks, construction equipments, and so on. The difference of velocities between left track and right one enables the vehicle to turn to left or right. Also, the vehicle can turn in its own radius by driving the tracks in opposite direction. This type needs only one actuating mechanism and operation can be done intuitively. However since the units of the tracks move on the ground with slip, it is difficult for the vehicle to go straight or to trace curved lines without any help of some kinds of control subsystems. The height of obstacles that the vehicle can climb over is determined by mainly the radius of sprocket for track belt, hence improving the height would need to enlarge the vehicle. Moreover, if the bottom side which is not covered by tracks get on an edge of obstacles, the vehicle becomes hung in the air. Using wider tracks would solve the problem, however, it results in increasing running and turning resistance. The vehicle cannot turn at worst caused by large resistance of the wider and longer tracks.

Fig. 4. Differential tracks, the right figure is ‘Frigo-D’ developed by National Research Institute of Fire and Disaster

2.2 Articulated Forward Tracks

When a rescue robot becomes stuck for a certain reason, articulated forward tracks (``Flipper tracks'') would be very effective to get out of the situation, e.g., Hibiscus (Koyanagi, 2006) has such tracks. The mobile robots with flipper tracks have been introduced to collect useful data in places inaccessible to humans at the area of WTC disaster, and the effectiveness of the flipper tracks has been proven. However, the flipper tracks and body section of vehicle may get object between them, and the joints that connect them may entangle something soft or fibers, etc. Those would force the flipper tracks to be useless, thereby the vehicle to be out of control. Moreover, problems might arise due to adding the flipper tracks: less reliability, difficult operation, increase of overall weight. To solve one of the problems, there have been studies (Ohno et al., 2007) to control flipper tracks automatically to help the vehicles to climb stairs or traverse gaps.

2.3 Serially connected Tracks

Not only for traveling across the rubble, but also accessing to the interior of the rubble pile through voids or opening, many search robots have adopted an architecture: some track-equipped segments are connected through joints as shown in Fig.5. For example, Souryu-I, II, III, IV, V (Takayama & Hirose, 2003, Arai et al., 2004 & 2008), MOIRA (Osuka & Kitajima, 2003), KOHGA (Kamegawa & Matsuno, 2007, Miyanaka et al., 2007). This type of vehicles can turn by differential movement of a pair of tracks on each segment (Arai et al., 2008, Kamegawa & Matsuno, 2007, Miyanaka et al., 2007) and the movement of joints between segments. Vertical joint actuators give higher ability for climbing over steps than that of individual tracked segments. On the other hand, running resistance would be more. The demerit can be removed by using shorter tracks on each segment, however, that would increase the number of segments, hence result to increase the number of actuating mechanisms of tracks and joints.

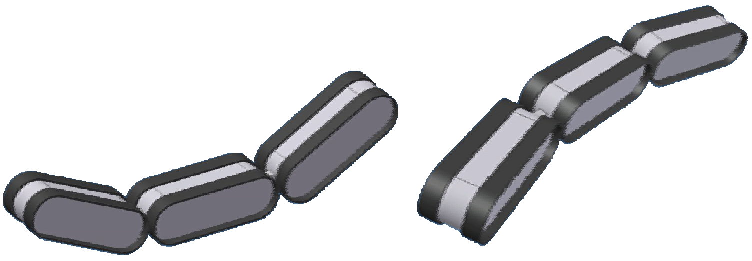


Fig. 5. Images of serially connected track

2.4 Mono-tread tracks

2.4.1 Serially connected mono-tread tracks

Souryu-V (Arai et al., 2008) has been the first vehicle which has the architecture that mono-tread track-equipped segments are connected through joints. The bottom side and top side of each segment are completely covered by track belts, hence the vehicle is hard to get stuck. Also that enables to avoid accommodation of debris between tracks and drive sprockets. On the other hand, if the vehicle turns with short turning radius, running resistance increases due to large slip friction between tracks and contacting surface. And stuck situation shown in the right figure in Fig.2 still might occur. Increasing the number of segments would increase the overall weight of the vehicle and complexity of the mechanism, as an inherent of the architecture.

2.4.2 Mono-tread mobile track

The serially connected track vehicles, which have extended bodies in longitudinal direction for access to the interior of the rubble pile, have the problems mentioned above due to the architecture. An idea to solve the problems might be to wrap around flexible body of a vehicle by only *one* track belt. Based on the idea, Fukuda (Fukuda, et al., 1994) have developed a robot which consists of only one mono-tread tracked segment, hence, mono-tread mobile track for cleaning the walls of buildings. The robot turns left or right by bending in shape around its yaw axis and climbs over steps by bending around its pitch axis. However, the bending around two axes rotate such as pivots, and the track belt is made of rubber, hence bending of the body is limited to be mild. Schempf (Schempf, 2003) have developed “AURORA” that can bend more laterally (net plus and minus 60 deg). But lateral bending has been realized by two rotational joints, thus its mechanism has been complicated. In addition, retro-flexion has not been enough to climb relatively high obstacles (over half of its height). Tanaka (Tanaka, 2006) has studied the realization of mono-tread mobile track that can bend more around each axis by using “flexible chain'' (which is described in detail below). The effort by Tanaka, et al. has been done almost at the same time as ours independently. But they have not yet implemented.

3. Flexible mono-tread mobile track

Then we propose a new mobile mechanism: Flexible mono-tread mobile track (FMT) to get over the problems as mentioned above and describe on FMT in detail in this section. FMT has only one track which wraps around the vehicle body. By employing ``flexible chain'' (see Fig.6) and vertebral structure (see Fig.7), the body flexes in 3D (see Fig. 8), and could flex much enough to change the direction of its head part. It is called ``WORMY''. Table I shows the basic specifications of WORMY and Table II the devices used for WORMY.

Fig. 6. Flexible belt: Configuration of belt segments (the left), Flexible belt (the middle) and belt with grousers (the right)

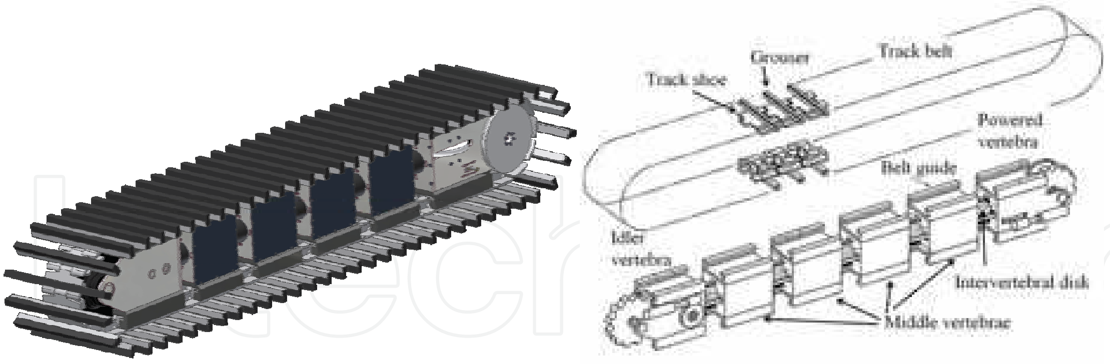


Fig. 7. Vertebral structure of FMT: 3D CAD image (the left) and its anatomy chart (the right)

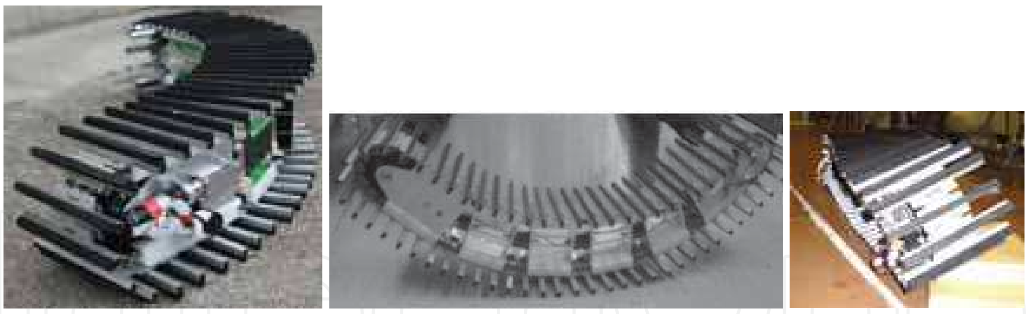


Fig. 8. Flexible Mono-tread Mobile Track (FMT). Lateral flexion (the left), retro-flexion (the middle) and twisting (the right)

Weight	Length	Hight	Width
12.4kg	1.2m	0.2m	0.2m
Vertebra {Ends (2 cells), Middle (4 cells)}			
Composite monocoque (CFRP,Aluminum,Plastic)			
	Intervertebral disk (5 cells)		
Rubber	ϕ40mm	length 40mm	
	Turning	Retroflexing	Twisting
Radius	640mm	750mm	-
Angle	±90deg	±70deg	±20deg

Table 1. Specification of the prototype WORMY

Track set	Tsubakimoto Chain Co.
Track belt	TPU-862-T ($R_{\min}$=500)
Sprocket	MB200-58641-SPR
Idler wheel	MB144-6633-IW
Motors	Maxon Motor
Track	RE30,GP32(679:49),MR
Flexion	RE30,GP32(24:5),MR
Gear and belt	
Track	Belt&pulley (6:1)
Retroflexion	Worm,Belt&pulley(24:1)
Lateral flexion	Worm,Belt&pulley(25:8)

Table 2. Devices of prototype WORMY

3.1 Mechanism for smooth flexing of the body

We adopted the vertebral structure for the body of WORMY. It consists of six segments as vertebrae and cylindrically shaped flexible materials such as rubber or springs are put between the segments as inter-vertebral discs. The flexible material allows a segment to rotate in small extent relative to adjacent segment around each of roll, pitch and yaw axes. Thereby, the body, as a whole, flexes in shape symmetrically around yaw axis (which is ``lateral flexion'') and around pitch axis (which is ``retro-flexion''), to make a smooth circular arc. Also, twisting around roll axis, the body conforms to rough terrain compliantly. Fig.8 shows the lateral flexion (the left), retro-flexion (the middle), and twist (the right). Actuators are located in both terminal segments to enable the body to have the lateral flexion and retro-flexion, as shown in Fig. 9. The first and the second figures from the left of Fig.9 illustrate the drive sprocket for the track belt and actuating mechanism for the lateral flexion, the first and the second figures from the right illustrate the idler sprocket and actuating mechanism for the retro-flexion. The actuating mechanisms for lateral flexion and retro-flexion employ toothed urethane belts. As shown in the left figure, the belt for lateral flexion is driven by a pulley and the both ends of the belt are fixed in another terminal segment (: Idler vertebra). Each segment has two holes for the belt which have been drilled in positions symmetry about the centre of the segment. The belt starts from the fixed point in Idler vertebra and goes through each hole made on a position of each middle segment, then goes around the pulley and returns to another fixed point through each hole made on another position of each middle segment. The tension caused by pulley deforms the rubber materials to result in uniform flexion of the body. Like-wise, WORMY can also retro-flex.

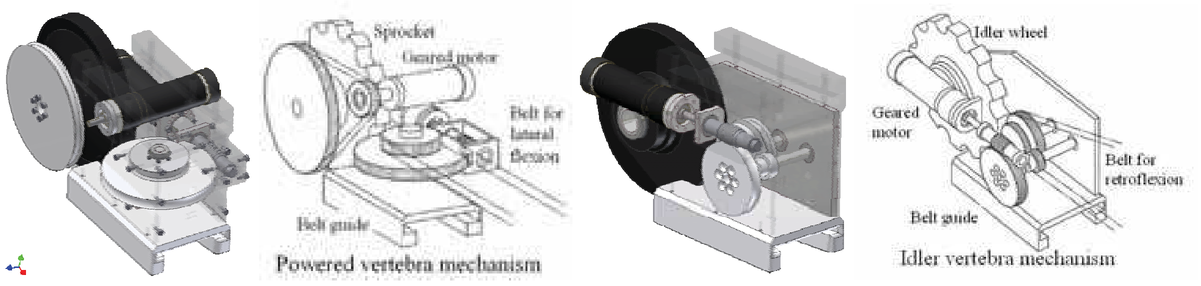


Fig. 9. Mechanism for track belt drive and flexion: Powered vertebra (the first and the second figures from the left) and Idler vertebra (the first and the second figures from the right)

3.2 Maneuverability

When FMT turns left or right, the turning radius is determined by the flexion of the body. Then, we can change the turning radius while the vehicle moves forward or backward, hence it is not difficult to let the vehicle to trace winding lines, moreover the slip would not arise between the grouser and the ground in contact area. These characteristics allow us to operate FMT in the same manner as car-like vehicles; we are familiar with how to drive (operate) them. Twisting motion of the body around roll axis is passive.

4. Geometry on the length of track belt for FMT

Since FMT employs the vertebral structure, when it retro-flexes, the track belt moves along a straight line between the vertebrae, i.e., in the part of inter-vertebral disc. Hence, as a whole, the track belt moves along a polygonal path to wrap around the body. Then the overall length of the track belt would be different between when FMT retro-flexes and when it is in straight line. The same situation would occur if FMT has other architecture: several segments connected by active joints. In the followings we consider on geometry on the length of track belt.

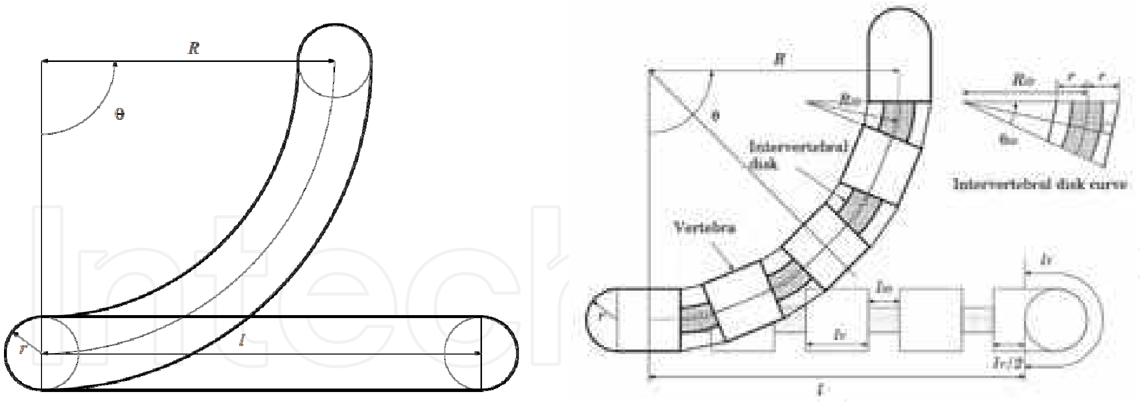


Fig. 10. Geometry on the length of track belt: Continuous flexibility (the left) and vertebral structure (the right)

4.1 In case of continuous flexibility

The left figure of Fig.10 shows schematic picture of side view when FMT retro-flexes and when it is in straight line. As shown in the figure, let l denote the length of centerline which connects the centers of drive sprocket and idler sprocket, r the radius of the sprockets. The centerline of the vehicle runs through the geometrical center of each cross section of the vehicle. As mentioned above, when the vehicle retro-flexes, it flexes symmetrically, hence the centerline comes to be circular arc. Then let R denote the gyration radius length and θ the central angle for the arc and we call the central angle as ``flex angle''. The left figure of Fig.10 shows the retro-flexion in case that θ is equal to $\pi/2$. The overall length of the track belt L_s when the vehicle is in straight line is described as

$$L_s = 2\,l + 2\,\pi\,r = 2\,(l+\pi) \tag{1}$$

Here, we assume that the body of the vehicle is continuously flexible; the arcs formed by the bottom side and top side of the body have the same center as that of centerline. And we also assume: $l = R\,\theta$. Then, overall length of the track belt L_r when retro-flexes is

$$L_r = 2\,\pi\,r + (R-r)\,\theta + (R-r)\,\theta = 2\,(R\,\theta + \pi\,r) \tag{2}$$

Using the assumption, we obtain $L_s = L_r$.

4.2 In case of vertebral structure

Next we treat FMT. Both terminal vertebrae have sprockets, then picking up the half length of the middle vertebra, we assign it to a part of the overall length of terminal vertebrae; the partial length of terminal vertebrae are taken to be involved in flexing. The number of vertebrae involving terminal ones is k+1, that of inter-vertebral discs is k. The right figure of Fig.10 shows the FMT with five vertebrae and four inter-vertebral discs. We assume the length of center line is conserved when it retro-flexes. Let l_V denote the vertebra length and l_{ID} the inter-vertebral disc, let R_{ID} denote the flex radius of the inter-vertebral disc and θ_{ID} the flexed angle of them as shown in Fig.10. Then,

$$R_{ID}\ \theta_{ID} = l_{ID} \tag{3}$$

holds. The length of track belt in the part of as inter-vertebral disc is

$$2\ (R_{ID} + r)\ \ \sin(\theta/2k), \tag{4}$$

at the bottom side of the body,

$$2\ (R_{ID} - r)\ \ \sin(\theta/2k), \tag{5}$$

at the top side of the body. Here, l_T denote the length shown in Fig.10. We can obtain the overall length of track belt Lr when retro-flexing:

$$L_r = 2\ l_T + 2k\ l_V\ + 2\ R_{ID} \sin(\theta/2k) \tag{6}$$

If k is large enough, $\theta/2k$ is small enough, hence $L_r = 2\ l_T\ + 2\ k\ (l_V + l_{ID})$. It means $L_r = L_s$ (:the track belt length when straight).

4.3 In case of multi segment mechanism

When a vehicle which employs the multi-segment mechanisms with joints bends its body, the shape should be polygonal: some straight line segments and corners. Universal joints are often employed to connect the segments for enabling the body to bend in 3D. If two active joints of one degree-of-freedom are combined to be one joint for connecting the segments, the body can bend to form shapes which consists of some different circular arcs, e.g., s-shaped line (see the left figure of Fig.11). We call them ``multi-arc-up-down flexion''. The overall length of track belt when retro-flexing gets near to that when straight if the number of joints increases and the length between segments decreases. The conclusion is the same as that in previous subsection.

4.4 In case of multi arc flexion

Next we give considerations on track belt length when FMT bends to form multi-arc flexion. The right figure of Fig.11 shows the side view when the vehicle retro-flexes and thereafter bends to be multi-arc-up-down flexion which consists of three circular arcs. We assume here that tangential line of each end of each arc coincides to that of adjacent arc and the length of centre line is conserved. Then the overall length of track belt when it flexes is expressed as

$$L_r = 2(\pi\ r + \Sigma_{i=1}\ \ l_i\ ) \tag{7}$$

where, n denotes the number of arcs. Using (7), we obtain

$$L_r = 2\ l_T + 2\ \Sigma\ \ l_i\ (l_T + l_{ID}) \tag{8}$$

where, super-script i means that the symbol with i is those for i-th arc. Equation (8) gives us a result that the track belt might loosen a little when FMT bends to form multi-arc flexion.

However, we can cope with that by adapting the tension of the belt or increasing the number of segments.

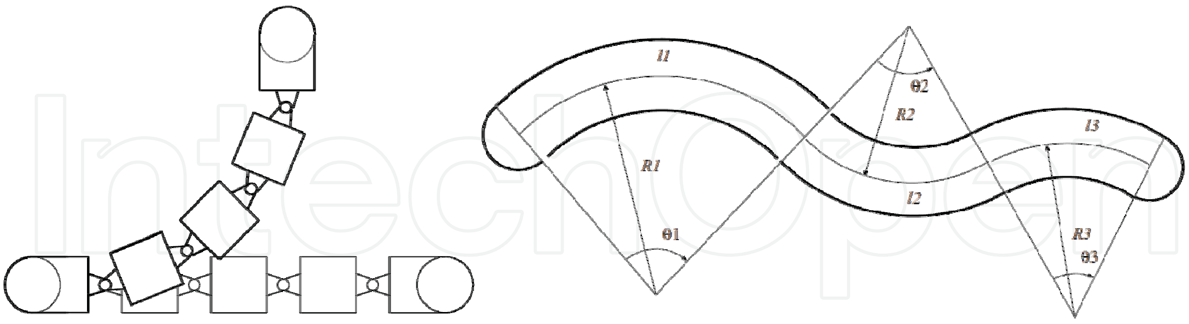


Fig. 11. Geometry on the length: Multi segment mechanism (the left) and multi arc flexion (the right)

5. Roll resistance of track belt in flexion

Roll resistance of the track belt of FMT varies depending on flexed angles when the vehicle retro-flexes and/or lateral flexion. It is worthwhile to make clear the characteristics of roll resistance for the purpose of speed control of the vehicle or autonomous mobility. Using WORMY, we have examined the relationship between flexed angles and roll resistance when WORMY lateral flexion. Travelling velocity of the vehicle has been proportional controlled to desired value. In experiments, the desired value was planned by using a step function which rises up to 1.25 m/s at the time 1s and get down again to 0 m/s at 8 s. P controller generates the control signal in voltage within the range of 5 V and outputs it to motor driver module. The module gives current to DC-motor which is proportional to the input. The left figure of Fig.12 shows the graph of velocity of WORMY versus time when it was in straight line, and the right figure the control signal (input to motor driver module) versus time. The graphs include waves of high frequency due to simple difference of angle data obtained by encoder. As is seen from the left figure of Fig.12, WORMY got to the velocity of about 1 m/s at about 1 s and maintained the velocity. As is seen from the right figure, the control signal (input) was about 4 V while WORMY was in the steady state. When the desired velocity rose up at 1 s, the control signal got up to saturate, hence, if we enlarge the range of control signal, the vehicle would get to steady state faster. Next, we have examined the relationship between the velocities in steady state and the control signals when the vehicle was turning on a flat plane. In the experiments, flexed angles were 0 deg, 30 deg, 40 deg, and 50 deg. The left figure of Fig.13 shows the graph of steady state velocity versus flexed angle. The right figure of Fig. 13 shows that the steady state velocity decreases and control signal increases as flexed angle increases and that the relationship is almost linear.

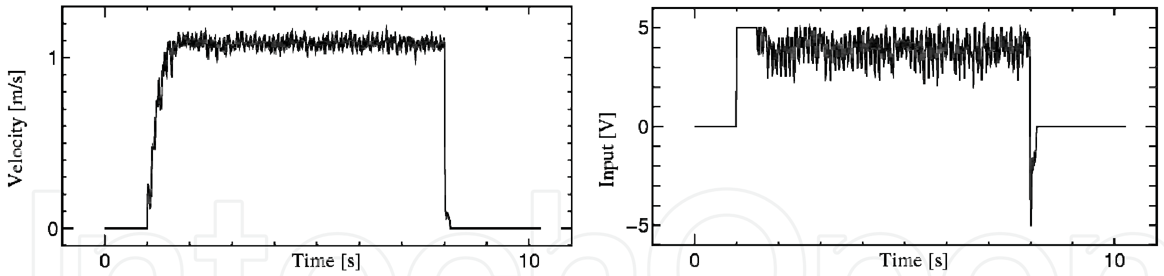


Fig. 12. Velocity and input voltage of prototype WORMY in case of straight posture: Velocity w.r.t. time (the left) and input voltage w.r.t. time

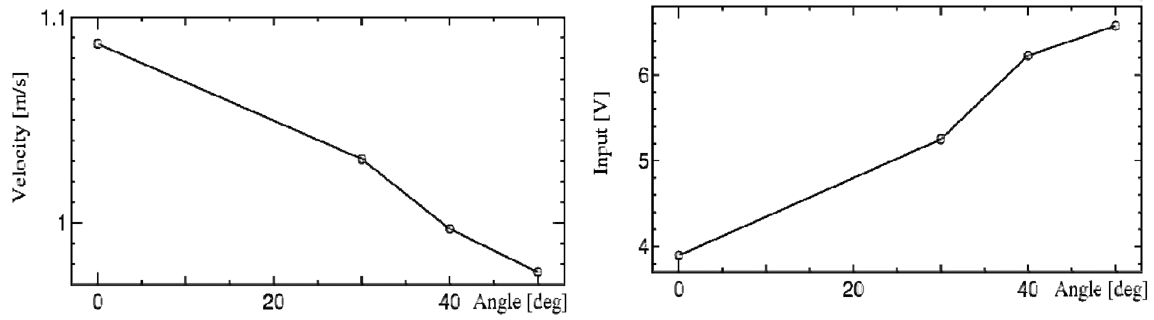
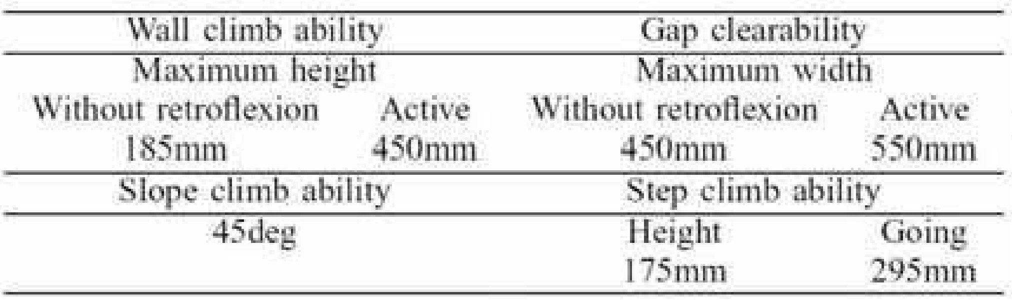


Fig. 13. Relationship between lateral flexion and track belt driving: Input voltage w.r.t. lateral flexion angle (the left) and velocity w.r.t. lateral flexion angle (the right)

6. Mobility

In order to assess the performance of WORMY, it has been tested. The test were basic ones; climbing over high steps, clearing wide gaps, climbing up and down stairs, and climbing slopes. Table 3 shows the performance of WORMY.



Wall climb ability		Gap clearability	
Maximum height		Maximum width	
Without retroflexion	Active	Without retroflexion	Active
185mm	450mm	450mm	550mm
Slope climb ability		Step climb ability	
45deg		Height	Going
		175mm	295mm

Table 3. Mobility of the prototype WORMY using battery (14.4 V)

6.1 Climbing over walls (steps)

Figure 14 shows the steps WORMY should take for climbing over a wall. First, the vehicle retro-flexes in front of the wall (0 s). Next, keeping retro-flexing it goes upward on the side of the wall (1 s). Then, leaning against the edge of the wall (2 s), it gets back to be straight (5 s) and goes forward (8 s). Finally, bending the body such that the head part turns downward, it goes forward (9 s). When the centre of gravity of the vehicle gets over the wall, it falls down on the ground to complete the task. As shown in Table 3, the maximum height is 450 mm by using retro-flex.

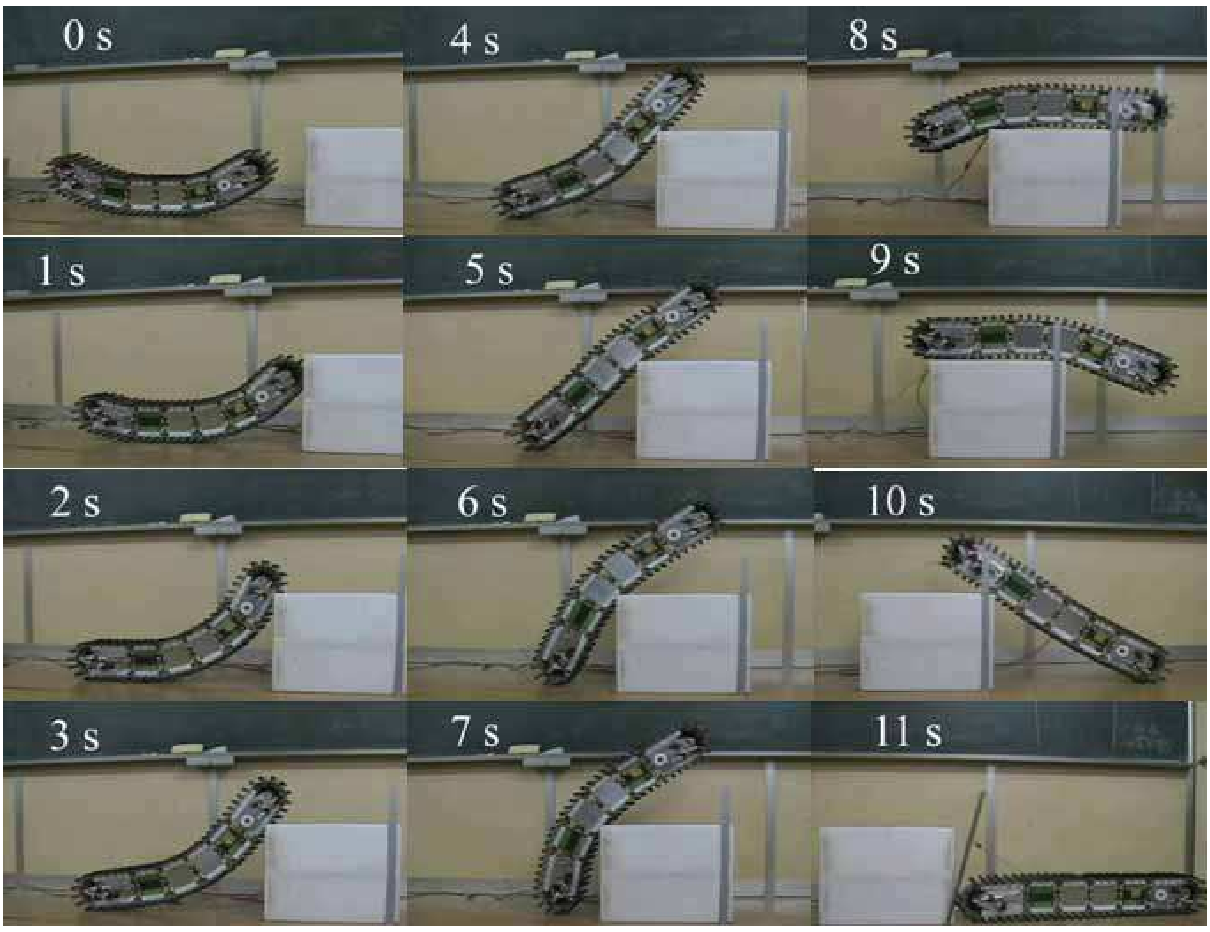


Fig. 14. Climb over walls (steps, height 450 mm)

6.2 Crossing ditches

Figure 15 shows the figures that WORMY traverses a ditch. In general, any robot can clear the gap whose length is shorter than the length between the front end of the robot and its center of gravity. Since WORMY has vertebral structure, the head part turns downward after it leaves the edge of gap if it goes forward without retroflex. Then, using retroflex it could clear the gap of 550 mm which is almost the same as the half length of WORMY.

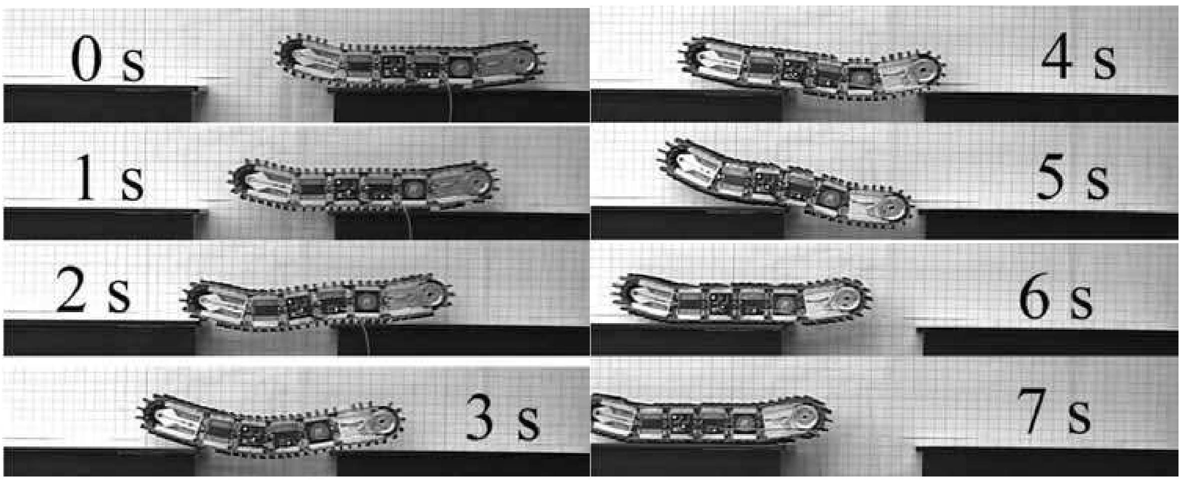


Fig. 15. Ditch crossing (width of the ditch is 550 mm)

6.3 Climbing slopes

Figure 16 shows the sequential photographs that WORMY climbs up a slope. We made slopes of inclined plywood whose length is 2 m. WORMY has been checked that it has enough power to drive up a 45deg inclined slope. We can ensure that it would climb up any slope of 45deg inclined if friction force is large enough.

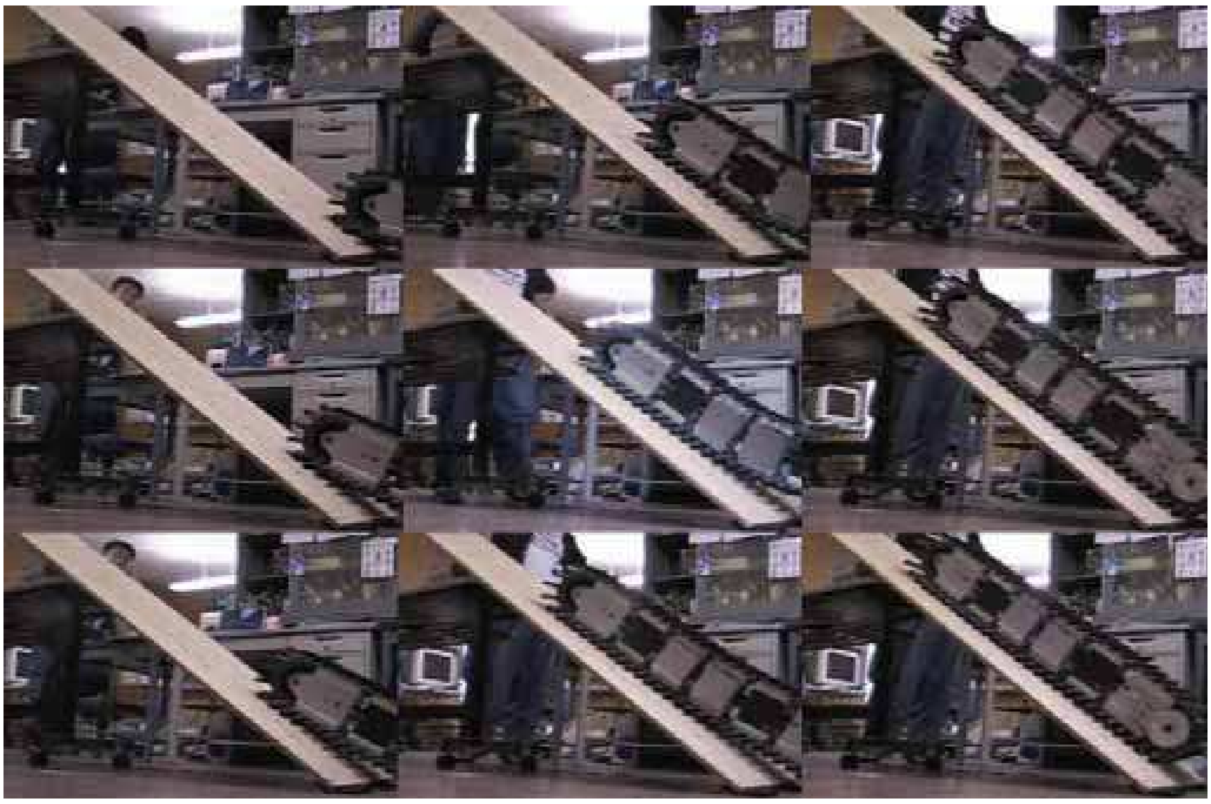


Fig. 16. Climbing slope (in case of 45 deg)

6.4 Climbing up and down stairs

We have tested WORMY using the existing stairs. Figure 17 shows the sequential figures that WORMY climbs up stairs. Figure 18 shows the schematic figure of the stairs that the vehicle could climb up. According to a standard for the design of stairs, we understood that the stairs in Fig.18 is close to those which are common in ordinary buildings. The stairs to subway station would be easily strewn with rubble to be hazardous and hard-to-reach after tragic events. The stairs to subway station are not so steep as that WORMY can climb up; the characteristics of a subway stairs are given in upper right corner of Fig. 18 as an example. We have found that when the vehicle goes down stairs, its head part passively turns downward, thereby impact force decreases which occurs when the body gets into contact with the tread of stairs. A problem has arisen that if the length of pitch line of the stairs coincides with the length that is equal to an integer multiplied by the length between two teeth, then the edges of treads of the stairs always get into contact on the part between teeth, thereby the vehicle might get stuck or lose grouser. WORMY would have a potential to climb up the stairs whose slope is 45 deg.

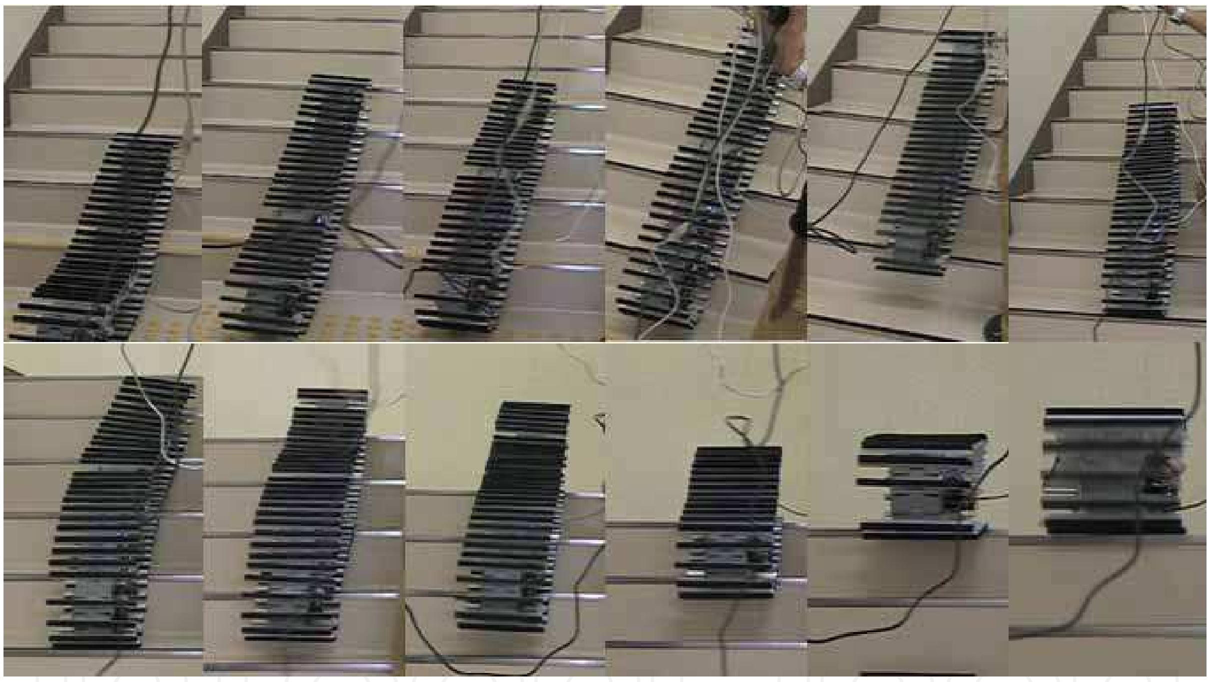


Fig. 17. Climbing up stairs

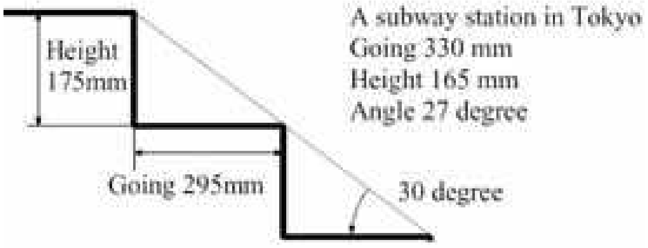


Fig. 18. Climbed Steps in experiments and an example of steps in public space

6.5 Plate Climbing

Figure 19 shows the thin plate climbing such that serially connected crawler may have some troubles. From the figure, FMT can climb over the thin plate without considering intrusion to joints by its slenderness. The serially connected crawler would be able to be recovered by bending or some other complicated mechanism such as puddles from stuck position. FMT has an advantage in the sense that it has no open joints and relatively large space.

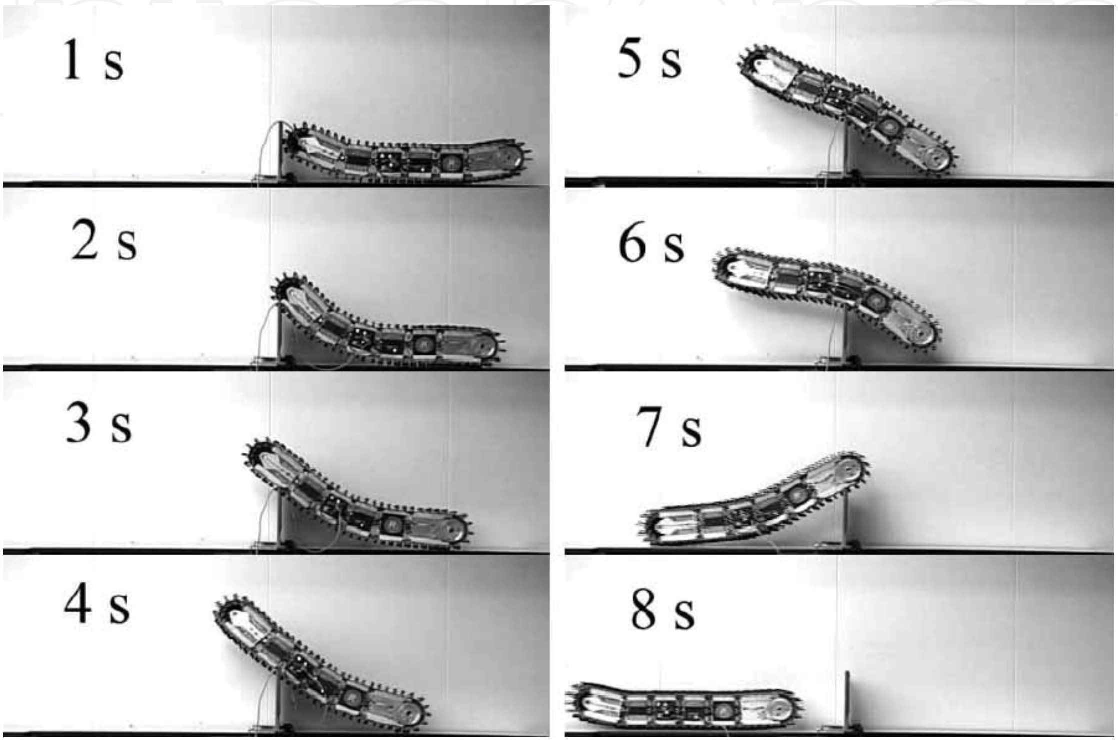


Fig. 19. Plate climbing (thickness 21 mm, height 300 mm and width 550 mm)

6.6 Recover-ability from lying position on its side

FMT has been checked that it can recover from lying position on its side. Figure 20 shows the sequential photographs that WORMY recovers from lying position. The test process is as follows: FMT is lying on its side (1s), retro-flexes upward (in direction of right hand side in the case, 2-4s), gets up by lateral flexion which makes center of FMT elevate (5-7s), and recovers to straight configuration.

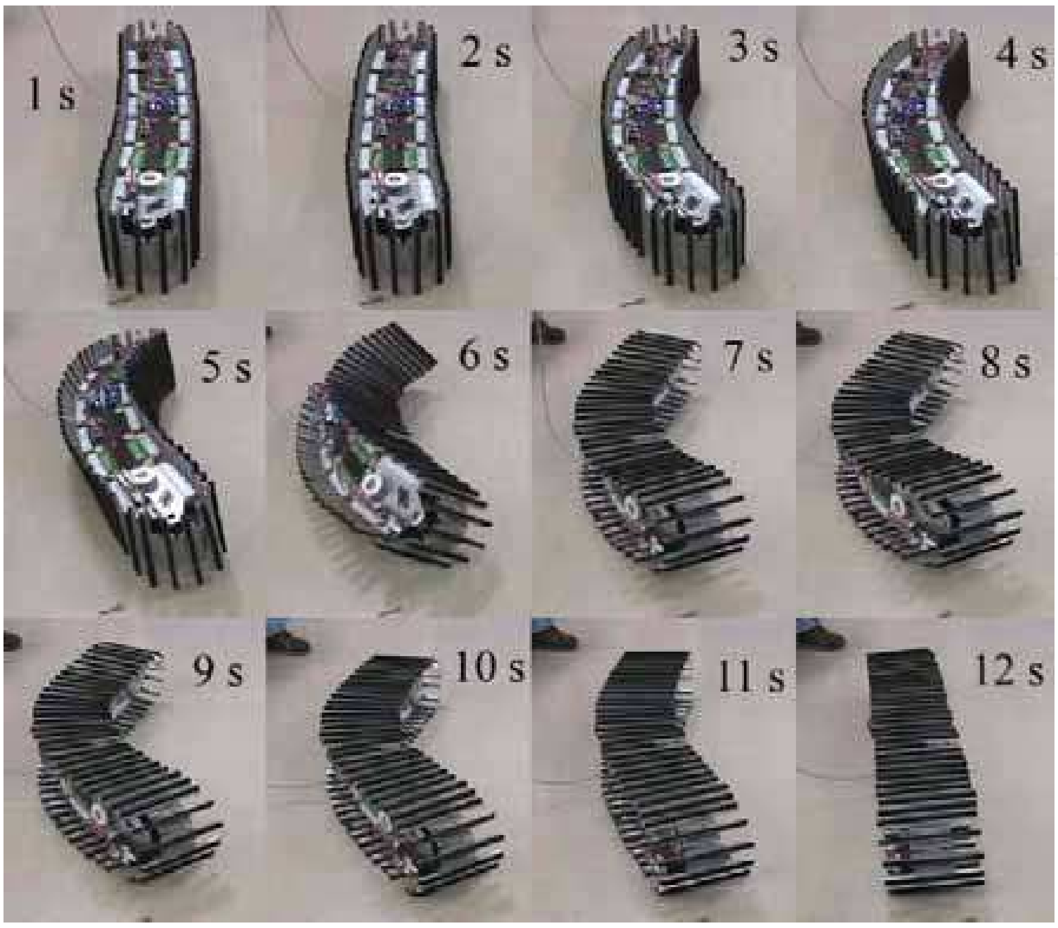


Fig. 20. Recover-ability from lying position on its side

6.7 Side winding

We have examined side winding through experiments using retro and lateral flexion skillfully. Figure 21 shows straight configuration (1s), upward retro-flexion which makes the both end vertebrae of FMT elevate (2s), lateral flexion (3-6s), downward retro-flexion which makes center of FMT elevate (8s), and recovering the straight configuration by lateral flexion (9-11s). As the result of the side winding, FMT could moves approximately 150 mm in lateral direction. Using the side winding, FMT can move lateral direction without track belt movement, and can avoid cutting back such as a non-horonomic system.

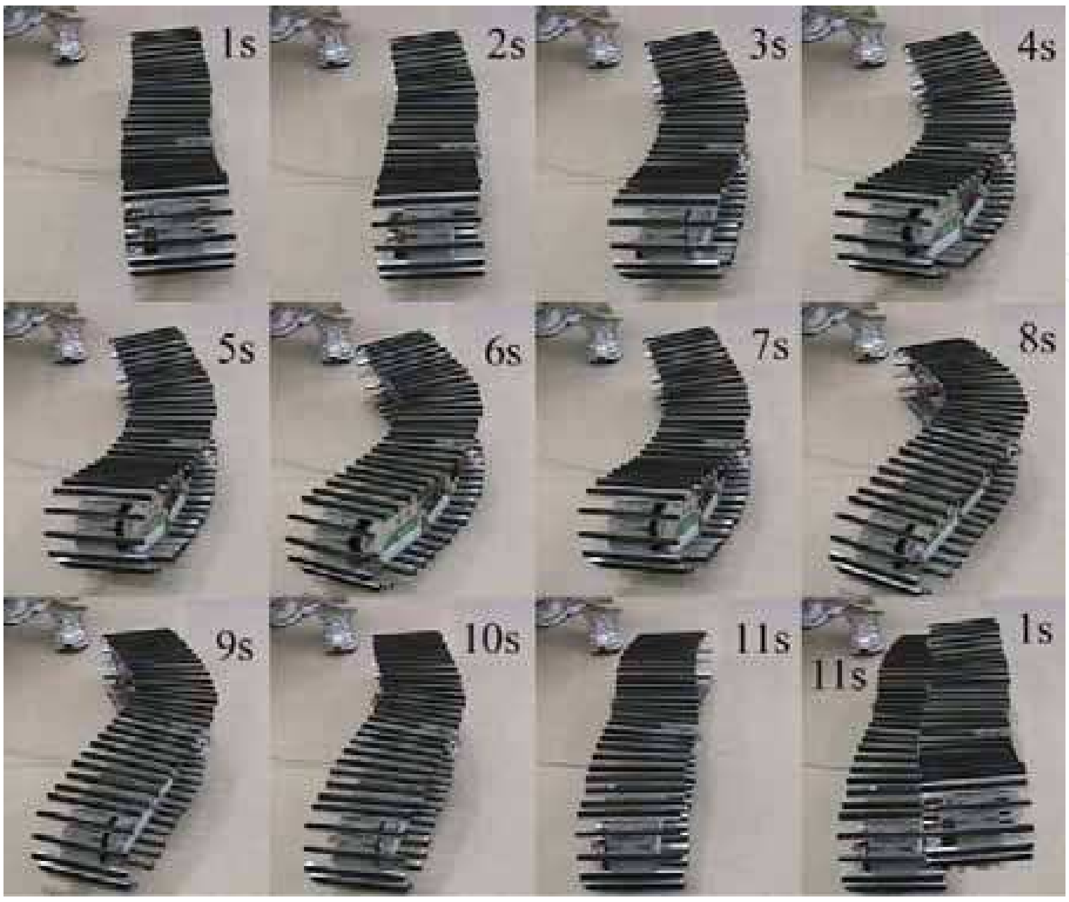


Fig. 21. Side winding

7. Conclusion

Serpentine robots, most of which have been developed as search robot, have high mobility on extremely rough terrain. However they have also some problems as described above. In this chapter we have proposed a new mobile mechanism: flexible mono-tread mobile track. It has the merits of serpentine robots and solved some of their problems. Key advantages of FMT are simple and light weight mechanism, covered by one track belt (FMT can recover even if FMT falls sideway) and 3D flexibility. Moreover we have developed a prototype ``WORMY'' and examined the performance on mobility. The followings are the important advantage of FMT:

1) Since the body is wrapped around by one flexible track, the vehicle has non-propulsion surface only on the sides of the body. Hence it can get around the problem of getting stuck on the edge of obstacles (FMT can recover by two way flexion even if FMT falls sideway).
2) Since the vehicle adopts vertebra-like structure and employs one actuating mechanism for flexing around each of pitch and yaw axes, the number of actuators would not change regardless of the overall length or the number of vertebrae (Light weight and simple mechanism can be achieved).
3) Since the body flexes smoothly in three dimensions, maneuverability is high, running resistance (slip) is less. The flexibility is effective against impact.

Dis-advantages are relatively large gyration radius, difficulty of smooth mechanism design for flexion such as belt, guide, tension and the number of segments, etc.

Future researches would be to equip various sensors on FMT for effective search of victims in search activity and to design a control scheme for autonomous movement.

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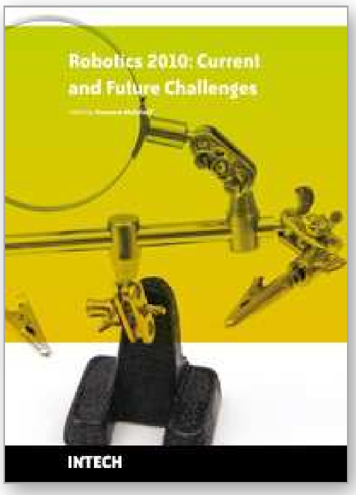

Robotics 2010 Current and Future Challenges

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Without a doubt, robotics has made an incredible progress over the last decades. The vision of developing, designing and creating technical systems that help humans to achieve hard and complex tasks, has intelligently led to an incredible variety of solutions. There are barely technical fields that could exhibit more interdisciplinary interconnections like robotics. This fact is generated by highly complex challenges imposed by robotic systems, especially the requirement on intelligent and autonomous operation. This book tries to give an insight into the evolutionary process that takes place in robotics. It provides articles covering a wide range of this exciting area. The progress of technical challenges and concepts may illuminate the relationship between developments that seem to be completely different at first sight. The robotics remains an exciting scientific and engineering field. The community looks optimistically ahead and also looks forward for the future challenges and new development.

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