Wall Climbing Robots with Track-wheel Mechanism

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***Abstract*—This paper presents a family of climbing robots that are using a track-wheel mechanism for locomotion mechanism. There are three robots: High speed vertical climbing robot, Flexible caterpillar robot, and Multi-linked climbing robot. The high speed vertical climbing robot uses suction pads to be attached on walls, and the robot has an advantage of high climbing speed of 14 m/min. The flexible caterpillar robot can configure its body shape according to external structure condition by using flexible joints. The robot is attached on the wall using segmented magnets. The robot can perform 90 degrees wall-to-wall internal transition without complex controller. The multi-linked climbing robot is composed of three main bodies that are controlled by kinematic relations. By using the three bodies, the robot can perform 90 degrees wall-to-wall internal transition. The adhesion mechanism is same with the High speed vertical climbing robot (suction pad). Mechanism description and experimental results are presented. The robots will be applied in wall cleaning and ship building applications.**

Keywords-climbing robot; track-wheel mechanism; high-speed climbing; transition.

I. INTRODUCTION

Wall climbing robots have been developed for decades to increase working efficiency and to ensure worker's safety. The robots are popular in various prospective applications such as cleaning, inspecting, painting, and blasting for high-rise structures. In the field of the climbing robots, locomotion mechanism design to enlarge the applicable areas of the climbing robots is the major issue.

Recently several wall climbing robots have been proposed using various locomotion mechanisms. NINJA-I, II [1–2] and RAMR [3] move using a legged locomotion mechanism, respectively. Sky Cleaner robot series [4–7] adopt translation locomotion mechanism. Alicia 1, 2 [8] and WallWalker [9] use wheel-driven locomotion mechanism. Cleanbot II [10], TRIPILLAR [11], and GEKKO III [12] move with track-wheel locomotion mechanism. Each wall climbing robot has its own characteristics of locomotion; therefore there are pros and cons for each locomotion mechanism according to the task of robot. Qualitative analysis on each locomotion mechanism is summarized in Table I.

TABLE I. The qualitative analysis of locomotion mechanism

Locomotion mechanism	Legged	Translation	Wheel-driven	Track-wheel
Climbing speed	slow	slow	fast	fast
Control complexity	high	middle	low	low
Transition ability	high	low	low	high

In this paper, three wall climbing robots using track-wheel mechanism are introduced: High speed vertical climbing robot, Flexible caterpillar robot, and Multi-linked climbing robot. The robot designs and features are presented in Section II. In Section II experiment results to demonstrate the mobility is presented. Concluding remarks are given in Section III.

II. CONFIGURATION OF TRACK-WHEEL WALL CLIMBING ROBOT

Proposed wall climbing robots are compared by its climbing speed, cost of control, and wall transition ability. High speed vertical climbing robot [13] is dedicated to rapid movement on vertical walls. Flexible caterpillar robot is for wall-to-wall transition without a complex control algorithm. Multi-linked climbing robot [14] is specialized in wall-to-wall transition in walls of various materials. Three wall climbing robots will be elaborated further in this section.

A. High speed vertical climbing robot

1) Configuration: High speed vertical climbing robot is designed for high speed climbing on a vertical wall. The robot configuration is shown in Fig. 1. The robot consists of two parts; main body and track-wheel system. Vacuum pump, power supply, control module, and actuation set for driving are installed on the main body. The track–wheel system consists of two timing belts with suction pads. Twelve suction pads with mechanical valve are installed on each belt as shown in Fig. 1. As the track-wheel rotates, mechanical valves are operated to open and close the vacuum air flow; so only the pads contatcting with the wall is operated to be attached. Main specifications of the robot are summarized in Table II.

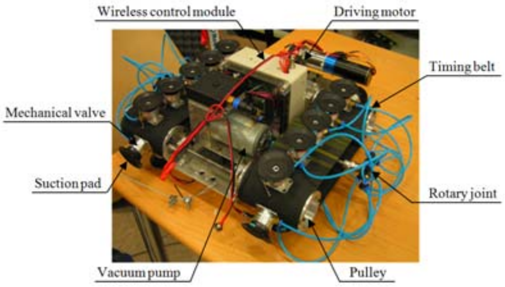

Fig.1 Configuration of High speed vertical climbing robot

TABLE II. Specifications of High speed vertical climbing robot

Items	Specification
Dimension	460mm x 460mm x 200mm
Weight (including battery)	14 kg
Actuator	One BLDC motor, Faulhaber, 200W (111:1 reduction)
Energy source	Li-ion polymer battery (25.9 V, 11 Ah)
Adhesion mechanism	Suction pad(24 EA), Φ60 mm

2) Experiments: To confirm the climbing performance of the robot, climbing experiment was fulfilled on a vertical wall as shown in Fig. 2. The robot can climb a vertical wall at a speed of 14 m/min.

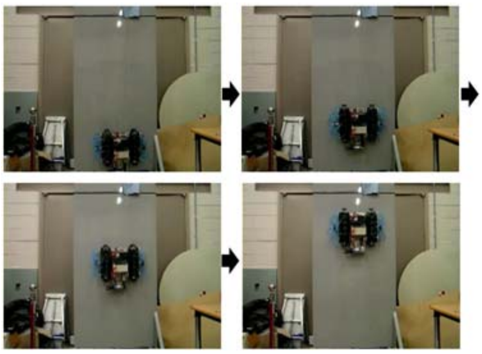

Fig.2 Experiment of High speed vertical climbing robot

B. Flexible caterpillar robot

1) Configuration: The robot is designed for wall transition and obstacle overcoming without complex control algorithm. The robot is shown in Fig. 3. The robot adopts transformable track-wheel mechanism which enables the robot to overcome obstacles by changing the configuration according to the wall shape. The mechanism is composed of a timing belt track with one driving actuator. The inner frame of the track consists of serially connected five rotational(R)-joints and one prismatic(P)-joint. All joints are designed with compliances to change the configuration of the robot so that it could adopt to the wall shape. Main specifications of the robot are summarized in Table III.

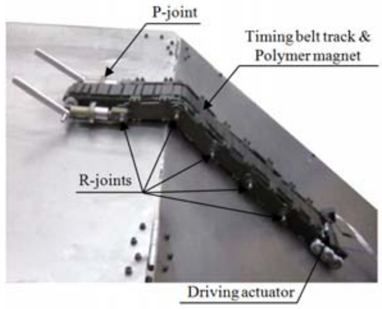

Fig.3 Configuration of Flexible caterpillar robot

TABLE III. Specifications of Flexible caterpillar robot

Items	Specification
Dimension	630mm x 200mm x 150mm
Weight	4 kg
Actuator	One DC motor, Maxon, 20W (318:1 reduction)
Energy source	24V DC power supply
Adhesion mechanism	Polymer magnet, 5t

2) Experiments: Wall-to-wall 90 degrees internal transition experiments were performed on a steel wall. The robot can perform the wall-to-wall transition using one motor without complex control as shown in Fig. 4.

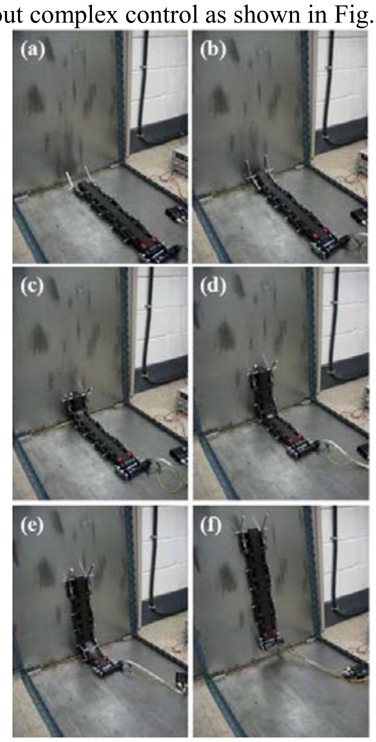

Fig.4 Experiment of Flexible caterpillar robot. a) Flexible caterpillar robot i s on the horizontal surface; b) Front wheel touches the vertical wall and the first link is detached from the horizontal surface; c) The first link is reattach ed to the vertical wall and the second link is detached from the horizontal s urface; d) The second link is reattached to the vertical wall and the third lin k is detached from the horizontal surface; e) The third link is reattached to t he vertical wall and the fourth link is detached from the horizontal surface; f) Flexible caterpillar robot adheres on the vertical wall and the transition of the robot is completed successfully.

C. Multi-linked climbing robot

1) Configuration: The robot is designed to enable various wall transition and obstacle overcoming on relativley rough surfaces. The robot configuation is shown in Fig. 5. The robot consists of three main bodies on which a track-wheel is installed. Two links are used to connect the main bodies. The robot is equipped with ten actuators; six for controlling the pitch of links, three for driving the track-wheels, and one for steering. Six suction pads are installed on each track-wheel for adhesion. Steering is performed using a large suction pad installed in the center of the second main body. The pad is pressed against the wall using a pneumatic cylinder and a motor is used to rotate the whole body relative to the suction pad. Main specifications of this robot are summarized in Table IV.

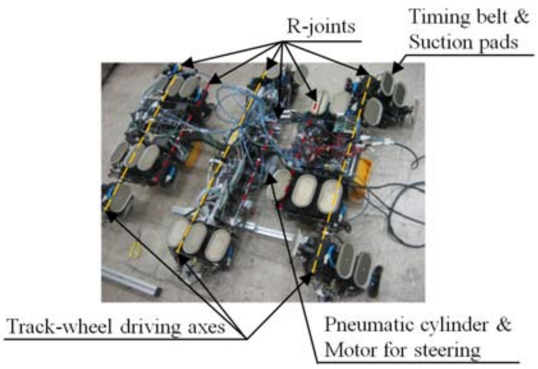

Fig.5 Configuration of Multi-linked climbing robot

TABLE IV. Specifications of Multi-linked climbing robot

Items	Specification
Dimension	1600mm x 1000mm x 300mm
Weight	70 kg
Actuator	Driving(3EA), Rotation(6EA), Steering(1EA)
Energy source	Vacuum pump(32L/min, 330W), Compressor(7bar), 24V power supply
Adhesion mechanism	Suction pads

2) Experiments: Wall-to-wall 90 degrees internal transition experiments were performed on floor to steel wall. Figure 6 shows the process of internal transition. The link actuators are controlled based on kinematic relations. As a result, the internal transition is completed successfully.

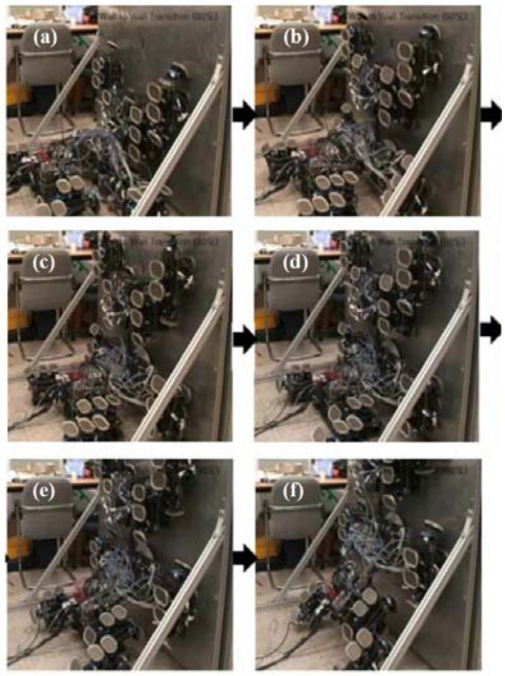

Fig.6 Experiment of Multi-linked climbing robot. a) The first main body is attached to the vertical wall and the second and third main bodies are attached to the horizontal surface; b) The second main body transfers from the horizontal surface to the vertical wall; c) The transfer of second main body is completed; d) The first and second main body climbs further to make room for the third main body to be reattached to the vertical wall; e–f)The third main body transfer from the horizontal surface to the vertical wall and the transition of the robot is completed successfully;

III. CONCLUSION

This paper described configuration and experimental results of the three wall climbing robots with track-wheel mechanism. Mechanical components of each robot are explained. The high speed vertical climbing robot was able to climb vertical walls at a speed of 14 m/min. The flexible caterpillar robot was able to perform 90 degrees internal transition without complex control, and finally the multi-linked climbing robot was able to operate 90 degrees internal transition with kinematic-based control. The proposed robots will be used in cleaning the walls of high-rise buildings and ships.

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