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Basic Study on Wall Climbing Root with Magnetic Passive Wheels

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Abstract— This paper deals with the wall climbing robot with magnetic passive wheels. The proposed robot consists of two driving wheels and 4 passive wheels with magnetic tire. The passive wheel is made by the combination with a suspension mechanism, a caster mechanism and a magnetic tire. The introduced passive wheel enables that the robot rides over a step or gap. At the result of experiments by the prototype, performance of smooth movement on the steel wall and riding over the 10mm gap is confirmed. The caster additionally realized the smooth change of direction.

Index Terms - Wall climbing robot; Magnetic force

I. INTRODUCTION

The maintenance applications for plants or buildings have been widely required recently. Drone technology is watched for such application, and various applications have been reported. On the other hand, demand of the wall climbing robot which operates direct inspection and maintenance to a wall of building is also increasing.

The author proposed the wall climbing robot on the smooth glass wall as shown in Fig.1 so far[1-2]. The developed wall climbing robot consists of vacuum suction cup and driving wheels, and can move smoothly on the glass wall without fall down. However, this robot can only move on the smooth surface because it is adsorbed on a wall by vacuum suction cup. In order to realize the adhesion on any surface, different mechanism of adhesion is required.

This paper proposed the wall climbing robot on the steel wall. Some plant building contains steel wall, especially, the chemical plant, e.g. an oil tank, and nuclear plant are made of steel wall and ceiling. In such plants, the inspection and maintenance are very important, and the robot which moves on the steel wall is required.

The developed robot consists of two driving wheels and 4 passive magnetic wheels. Additionally, the passive magnetic wheel is organized by the suspension mechanism and caster mechanism. The suspension mechanism enables that the robot can ride over the step, and the caster mechanism can change the direction of movement easily. This paper reports the basic design of mobile robot with magnetic caster, and the properties through some experiments.

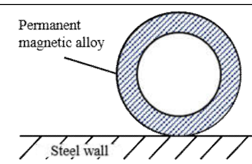
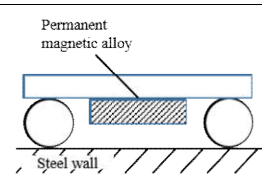
II. WALL CLIMBING MECHANISM ON STEEL WALL

Several mechanisms of adhesion on the steel wall or ceiling are proposed so far. They used permanent magnet for adhesion n the steel wall. Osaka Gas Co. Ltd. developed the stable moving robot with magnetic tires. Hirose et al. proposed the inclining magnetic tires for increasing the magnetic force.

Table 1 overviews the future of magnetic adhesion mechanism for a mobile robot. Adhesion by the magnetic force are categorized into two way: One is the direct contact by magnetic wheels, and another is the non-contact adhesion by permanent magnetic alloy.

Figure 1. Wall climbing robot: WallWalker

TABLE I. MAGNETIC ADHESION MECHANISM

System	Mechanism overview
Direct contact adhesion by magnetic wheel	
Non-contact adhesion by magnetic block	

The magnetic driving wheel like as Osaka Gas Robot enables stable movement, but it is difficult to change the moving direction. Moreover, it is impossible for the magnetic wheel to ride over the gap or step.

The non-contact adhesion system can easily keep the stable adhesion condition, if it is possible to hold the constant distance between the wall surface and the magnetic alloy. However, since it is difficult to keep the gap between the wall surface and magnetic alloy, this adhesion system is not suitable for high-speed movement and moving on rough surface including steps.

The magnetic force is decided by the surface area of magnetic alloy. Therefore, the non-contact adhesion system, of which surface area is easily widened, can be designed for increasing the adhesion force. Besides, since it is necessary to keep the magnetic alloy in parallel against the adhesion surface, it is generally impossible to apply this system into the application on the curve surface or the surface including setps. Hirose et al. proposed the way of widening the surface area of driving wheel, but the realization of practical system is disturbed by complexity of mechanism.

Except the magnetic adhesion system to steel wall, there is the way of movement by pressing the robot onto the wall by wind power. However, this way needs high consumption of power, and it is difficult to apply this method into the practical application. On the other hand, the flexibility of movement of this method is better than the magnetic adhesion, and this way is suitable for the performance on the vertical wall.

This research proposes the adhesion system by sub-wheels of magnetic alloy. Additionally, in order to increasing flexibility of movement, the caster mechanism is introduced into the sub-wheels. These two mechanism realized the flexibility of movement compared with the conventional way of magnetic adhesion system.

III. Basic Structure of Magnetic Caster

Figure 2 illustrates the basic structure of new mobile mechanism by magnetic sub-wheels. The robot consists of a driving unit with two combinations of a DC motors and a wheels, and an adhesion unit with four magnetic sub-wheels.

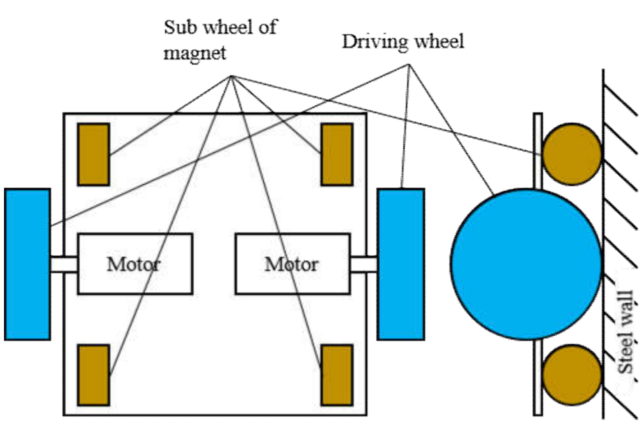


Figure 2. Basic Structure of Mobile Mechanism by Magnetic Sub-Wheels

It is easy to design the adhesion force by number of sub-wheels made of magnetic alloy. Figure 2 shows a sample of proposed mechanism in case of 4 sub-wheels. However, because directions of driving wheels and sub-wheels are equaled, it is difficult to change the direction of movement. For solving this problem, we introduced the caster mechanism for the sub-wheels as shown in Figure 3.

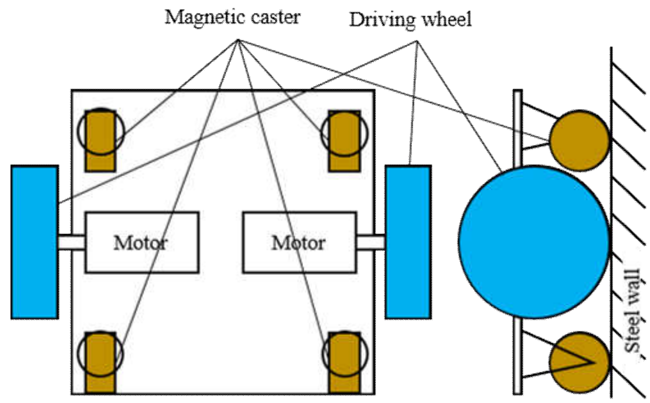


Figure 3. Basic Structure of Mobile Mechanism by Magnetic Casters

First, we considered to use the ball-caster as the caster mechanism, but a diameter of ball is so small that it is difficult to ride over the step. 2/3 of the radius of the wheel is the height of the step which the robot can ride over as general theory. According to this theory, the wheel-caster is more suitable than the ball-caster, since the diameter of wheel is easily expanded.

The shock absorbing caster produced by SISIKU ADDKREIS Corporation as shown in Figure 4 is unique to realize the compact architecture of caster and suspension. The proposed robot was designed using this shock absorbing caster.

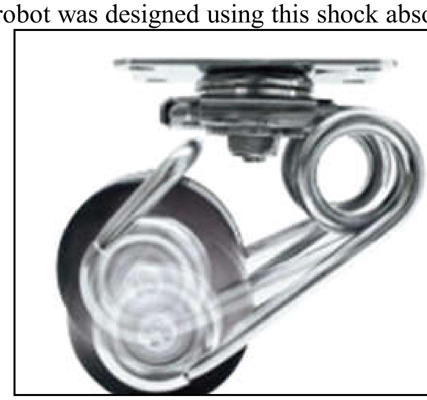


Figure 4. Suspension-Caster (SISIKU ADDKREIS Corporation)

The shock absorbing mechanism is effective for riding over the gap and step. When the robot takes over the gap, the height contacting on the surface of driving wheels and sub wheels of magnetic alloy were become different. The introduced shock absorbing mechanism adjusts such difference of contacting to the surface.

IV. Prototype of Mobile Robot with Magnetic Caster

Figure 5 illustrates the prototype of mobile robot with magnetic caster, and Table 2 is the summary of specifications of prototype. The body of robot is made with aluminum alloy, because the body did not undergo influence of magnetic field from the magnetic caster. It is also confirmed that motors did not undergo influence of magnetic field by experiments.

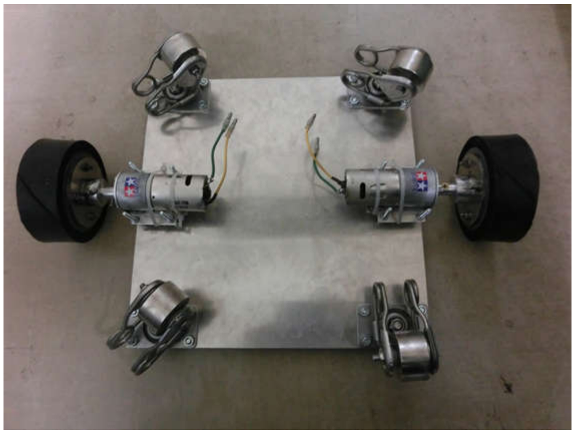


Figure 5. Bottom view of Prototype of mobile robot with magnetic caster including suspenson mechanism

TABLE II. SPECIFICATIONS OF PROTOTYPE OF MOBILE ROBOT WITH MAGNETIC CASTER INCLUDING SUSPENSION MECHANISM

Subjects	Data	Unit
Demension	440 x 300 x 120	mm
Weight	3.3	kg
Driving Wheel	Diameter 120 Width 35	mm
Motors	Tamiya 380K300	
Caster	SISIKU ADDKREIS Corporation SASUJ-TS6-50R	
Magnetic Wheel	Neodymium magnet: ϕ41x 23	mm

As shown in Figure 5, the prototype is made by two units of motor and driving wheel, and four magnetic casters including suspension mechanism. Figure 6 shows the overview of magnetic caster, which of wheel is replaced into the magnetic wheel. Neodymium magnet was used as the magnetic wheel. As the basic part, the shock absorbing caster SASUJ-TS6-50R produced by SISIKU ADDKREIS Corporation as shown in Figures 5 and 7 was utilized. Table III is about specifications of caster SASUJ-TS6-50R. The fork and magnet wheel don't intervene in each other, because the spring fork of this caster is made of stainless steel.

Figure 6. Overview of magnetic caster with suspension system

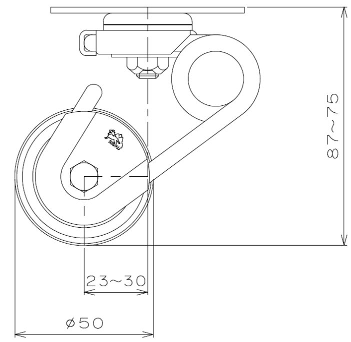


Figure 7. Skematic design of shock absorbing caster SASUJ-TS6-50R

TABLE III. SPECIFICATIONS OF SHOCK ABSORBING CASTER SASUJ-TS6-50R (SISIKU ADDKREIS CORPORATION)

Total height	Diameter of tire	Width of tire	Permmisible load	Buffered load
87-75 mm	50 mm	25 mm	30 kg	40 kg

TABLE IV. SPECIFICATIONS OF NEODYMIUM MAGNET TIRE

Outside diameter	Inside diameter	Width	Surface inductive flux	Adsorption force
41 mm	14 mm	23 mm	476.5 mT	44 kgf

Table IV is summary of specifications of neodymium magnet tire introduced into the suspension caster. The diameter of wheel of based caster is 50 mm, but the replaced magnetic wheel is 41 mm.

The important point of design is the setting of height of driving wheel and adhesion wheels. The balance between the adsorbing power by magnetic wheels and the traction force by driving wheels decides the propulsive force of robot. This balance can be calculated by the above setting of height.

Figure 8 explains the basic setting of driving wheels and magnetic wheels. The sub-wheels are replaced to the magnetic casters. In this mechanism, the initial height of driving wheels and magnetic casters.

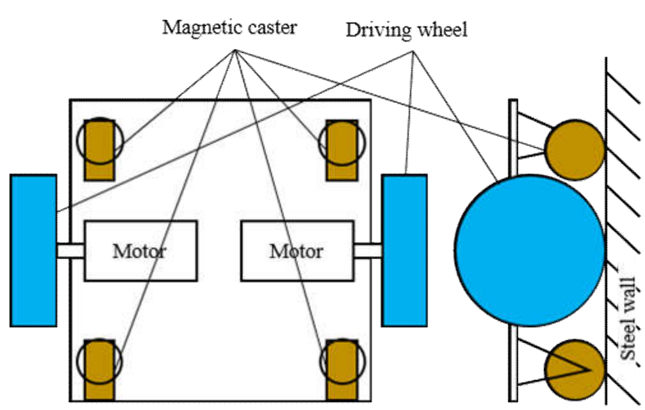


Figure 8. Setting model of heights of driving wheels and magnetic casters

V. Properties of Mobile Robot with Magnetic Caster

First, we tested the mobility of prototype on several condition of wall. As shown in Figures 9 and 10, the developed prototype can move on both of vertical wall and inclining wall. This chapter reports some properties illustrated by experiments.

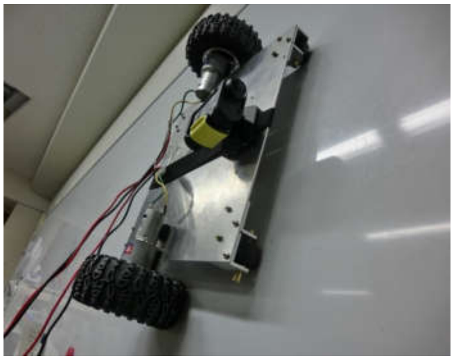


Figure 9. Performance on the virtical wall

Figure 10. Performance on the inclining wall

A. Characteristics of Magnetic Caster

The developed robot is adsorbed on the steel wall by very strong magnets. When the robot begins to move from a resting state, it is an important problem whether a magnet wheel can move smoothly. Figure 11 shows the initial setting of direction of magnetic casters and the direction of pulling force. As the results of experiments on the setting as shown in Figure 11, the propelling forces for moving the robot were measured as shown in Table IV.

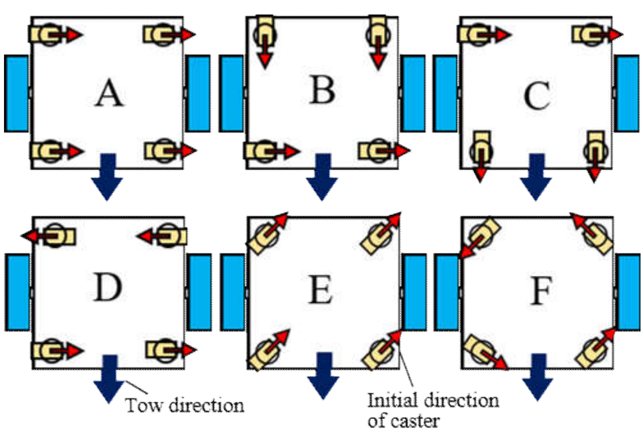


Figure 11. Initial setting of direction of magnetic caster and direction of pulling force.

TABLE V. Tow Force for Beginning to Moving

Setting	A	B	C	D	E	F
Tow Force [N]	24.0	16.9	14.1	25.5	24.4	21.3

As a result of experiments as shown in Table IV, a necessary force for beginning to move in case of including casters parallel to the tow direction was smaller than that force in case of including casters vertical to the tow direction. The reason why tow force of setting A is smaller than the setting D is that the direction of caster of setting A easily gathers because the caster direction of setting A is set toward the straight movement compared to the setting D which is set for turning.

B. Basic Properties of Prototype

Table VI shows the basic performance of developed prototype as shown in Figure 5.

TABLE VI. Basic Characteristics of Developed Prototype

Subjects	Data	Unit
Dimensions	Width 440 Length 300 Height 120	mm
Weight	3.3	kg
Speed (maximum)	Vertical (upward) 0.22 Horizontal 0.34	m/s
Mountable load	3.3	kg

When the robot moves downward, in order to prevent from falling by gravity by friction of a wheel, the max speed can't be established. Safe mobile speed downward without a slip was 0.28m/s.

When setting a caster vertically to the movement direction like A on Figure 11, meander was observed a little when start of moving. This meander is necessary movement for having complete set of the direction of the caster, and about 10 mm of orbit shift was observed from a video. It is important to reduce the drift of orbit against the target trajectory.

About a response of starting of moving, Table VII shows the time from resting state to the maximum speed. The experimental results indicate almost same results like the experiments of tow force as shown in Table V. As the results of experiments in Tables V and VII, it seems difficult to change the direction rapidly.

TABLE VII. Tow Force for Beginning to Moving

Setting	A	B	C	D	E	F
Avarage time for resting state to maximum speed [s]	1.15	0.85	0.92	1.32	1.28	1.25

C. Basic Properties of Prototype

The proposed robot is designed for the movement on the steel wall. Since a steel wall is made by connecting the steel plate by welding, the robot is required to ride over the weld line. Figure 12 shows the common weld line, which of height is 5-7 mm and width is 5-10 mm.

Figure 12. Weld line

Figure 13. Experimental settinf of riding over the door joint

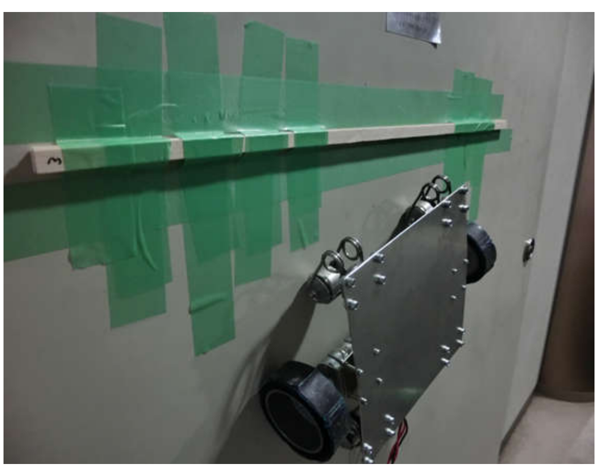


Figure 14. Experimental setting of Performance on the inclining wall

Figures 13 and 14 shows the experimental setting of riding over the projection. In the experiments of Figure 13, riding motion of robot against natural projections as like the door joint was tested. The experiments as shown in Figure 14 measured the shape of projection.

As the experimental results, the maximum height of projection was 11mm, and width is 18mm. However, the robot could not ride over the projection when the robot approaches to the projection vertically. In such case, since two front magnet casters were detached from the steel wall at the same time, the adhesion force became lack against maintaining the robot on the wall.

The developed prototype was as least confirmed to ride over the projection like as the weld line, but the condition of riding over was limited. As the results, the robot could not take over the projection when the robot approached to the projection vertically. For applying this robot into the practical use, this problem must be solved.

Table VIII shows the summary of experiments of riding over the steps. Those experiments measured the width and height of projection against setting of driving wheels.

TABLE VIII. EXPERIMENTAL RESULTS OF RIDING OVER OF PROJECTION

Setting of driving wheels	Width of projection	Height of projection
15mm	12mm	14mm
16mm	12mm	13mm
17mm	11mm	12mm
18mm	11mm	12mm

VI. CONCLUSION

This paper proposed the mobile robot on the steel wall, which consists of magnetic caster with suspension mechanism. The developed prototype moved on the steel wall smoothly, and could ride over the projection like as weld line.

This study proved that the proposed mechanism can realize the robot which moves on the steel wall. Moreover the caster mechanism realized flexible motion on the steel wall. Especially, the proposed robot easily change its moving direction.

On the other hand, some problems are still remained as follows.

- When the robot rides over the projection, the robot cannot take over it vertically.
- The condition of setting of heights of driving wheels and caster wheels influents into the traction force.

As the next step, we try to solve the above problems and develop the practical mechanism for the robot which can be applied into the practical use.

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