

## Development of Wall Mobile Robot for Household Use

Takahiro DOI\*<sup>1</sup>, Kenta SHIROTORI\*<sup>1</sup> and Ken ITO\*<sup>1</sup>

\*<sup>1</sup> Kanazawa Institute of Technology  
Department of Robotics  
3-1, Yatsukaho, Hakusan city, Ishikawa, 924-0838, JAPAN  
doi@neptune.kanazawa-it.ac.jp

### Abstract

Increasing aged people who needs nursery care, shortage of care-giver is getting serious. Robot technology is one of the most promising solutions for this problem. Mobility is indispensable function for household works. However, it is not easy to move in houses usually, because there are inevitably obstacles on the floor (steps, clothes, etc.) and the environment is not flat. This paper proposes a simple and feasible indoor robot system that consists of a wall traversing platform and robot arm. The design of traversing mechanism and basic experiments are shown.

**Keywords:** wall traversing, home robot

### 1 Introduction

Many robots that have wheeled mobile mechanisms are designed for welfare and household works in houses [1], [2]. However, it is not easy to move in the house by simple wheels usually because there are obstacles and steps on the floor and the environment is not flat. Thus these robots need additional mechanisms, sensors and controls for adapting uneven environment in houses. Conventional robots that work for welfare/household tasks in houses must move on this uneven floor and manage tasks at the same time. Those robots must have such a heavy cost in mechanical design and control just for the mobility.

Instead of the floor, a wall may be a proposing field for household robots to move. Some mechanisms for inspection, cleaning or painting that exploit vacuum or magnets have already been proposed [3][4], however, these mechanisms need a large wall which is extremely flat for suckers or made of iron for magnets, which is hardly seen in houses. And the control of the adhering mechanism is not easy.

We propose a system that consists of rails on the wall and moving platforms that can move on the rails and have a robot arm, as a solution for mobility and task in a house. This system realizes a simple robot system that can move and handling objects at the same time.

## 2 Wall Mobile Robot

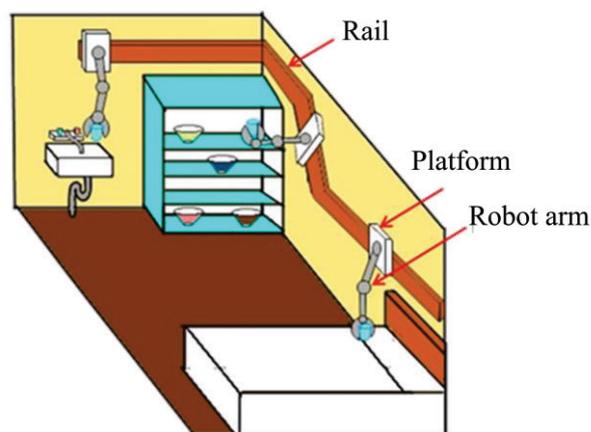
### 2.1 Concept

This paper proposes a system that has a moving platform that move along rails fixed on the wall and a robot arm implemented on the platform (**Fig. 1**).

The advantages of this system are: 1) moving ability regardless of steps or obstacles; 2) reach to high place

far from ground with rails; 3) high stability with the reaction force from the walls and rails.

In this paper, the moving platform of the robot is introduced.



**Fig. 1 Concept**

In the design of the moving platform, a special mechanism for supporting force and moment that come from weight of the robot system and payloads, on the rail is needed. The mechanism also needs to move and follow the rails that are curved vertically and horizontally, without running off.

In a research of robotic room - a robot system built in a room – moving platform with robot arm on a dedicated rail on the wall and help patients in a hospital is proposed [5]. A moving platform on a ceiling is also proposed [6]. A lifter system for stairs is commercially available [7]. These are large system and dedicated rail or infrastructure must be built in a room. Hence it tends to expensive and occupies too much space.



**Fig. 2 Handle rail**

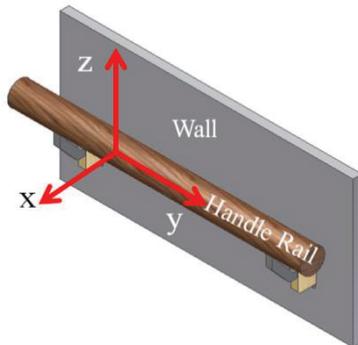
Handle rails for houses in **Fig. 2** are used as rails for the moving platform. Because the handle rails can be often seen in houses generally around the steps and they are standardized and commercially available. Installation of them is easy and their strength is enough to support robots.

## 2.2 Statics of the Robot

In order to make the robot follow the rails that are curved vertically and horizontally and keep its position on the rail and support its weight, the arrangement of the tires and the handle rail are discussed. There are several tires and casters in the robot system which touch the handle and wall and get reaction forces.

The coordinate system is arranged as **Fig. 3** against the handle rail and the wall. The x-axis is perpendicular to the wall, the z-axis is along the vertical direction and the y-axis is the direction that makes the right-hand system with the x and z axes. The origin of the coordinate system is the center of the handle.

When the proposing mechanism is installed on and moves along the handle, the gravitational force of the weight acts in z-direction and the force of payload weight make a moment of force around y-axis. Getting reaction force from handles and walls near the robot by tires, the equilibrium is established.



**Fig. 3** Coordinate system

**Figure 4** shows the equilibrium of the force of the mechanism from tires and casters in xz plane. There are a driving tire touching the upper face of the handle to support vertical force and a wall caster (e) pushing the wall in x direction. The force that the handle pushes the driving tire in vertical direction  $F_1$ ; the friction between the handle and the driving tire  $F_2$ ; the position where these forces is  $(x_1, y_1, z_1)$ ; the force that act on wall Caster (e)  $F_3$ ; and the position is  $(x_3, y_3, z_3)$ . The external force of the robot is  $F_4(F_{4x}, F_{4y}, F_{4z})$  on  $(x_4, y_4, z_4)$ , and gravitational force is  $W(0,0,W)$  on  $(x_G, y_G, z_G)$  (center of gravity). Disregarding the effect of support casters the forces  $F_1, F_2, F_3$  can be expressed in the following equilibrium equations:

$$F_1 + F_{4z} + W = 0 \quad (1)$$

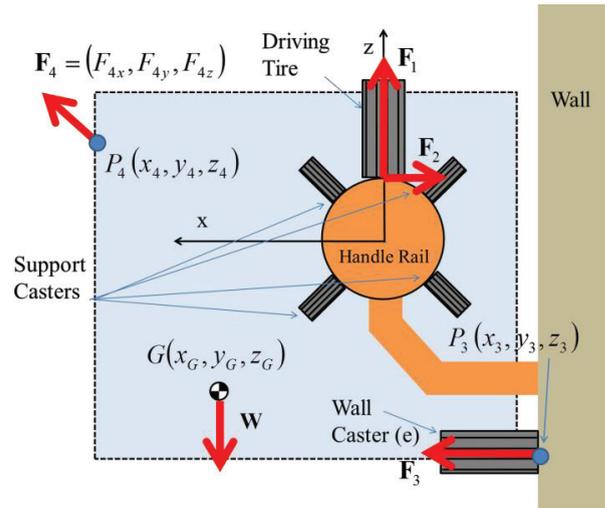
$$F_2 + F_3 + F_{4x} = 0 \quad (2)$$

$$F_3 z_3 - W x_G - x_4 + F_{4x} z_4 + F_2 z_1 = 0 \quad (3)$$

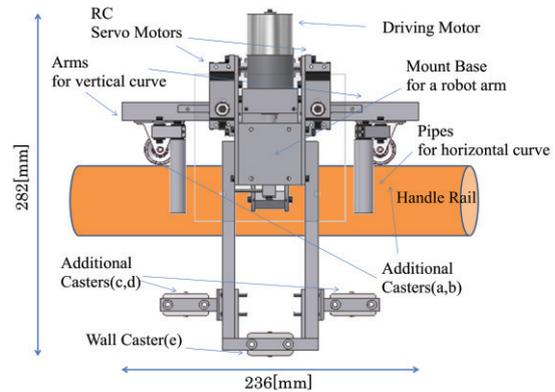
If a tire gets strong force, the driving axis of the motor

also get bending force, output power is reduced by the friction or deformation and it is difficult to keep the posture of the robot. Hence, four casters (c), (d), (e), (f), are added to support the weight of the robot. The equations of equilibrium with support casters are almost the same as (1), (2) and (3) with support casters. The robot system gets forces  $F_1, F_2$  from support casters instead of driving tire. With support casters, the robot system can get reaction forces of all direction in x-z plane and the load of driving tire is reduced.

The curves of the handle can be classified to vertical (curves in yz plane) and horizontal (curves in xy plane). In order to adapt these curves, several additional casters and active/passive mechanisms are introduced.



**Fig. 4** Forces around the robot



**Fig. 5** Front view

## 3 Mechanism and Control

### 3.1 Mechanism

A prototype of moving platform on handle is manufactured. A front view of the moving platform and a side view (inner structure) are shown in **Figs. 5 and 6**, respectively. The moving platform weighs 2.06[kg] and consists of a DC geared motor (TAMIYA 3633K300) for the driving tire; RC servo motors (GWS S03T 2BBMG) to drive the arm of the casters; a driving tire, a wall caster (e); four support casters; and four additional casters (a), (b), (c), (d). The two casters above (a), (b)

keep the rotational posture around x-axis, two casters below left (c) and right (d) keep the rotational posture around z-axis, and the wall caster below center (e) keeps the rotational posture around y-axis. Weight of the platform is supported by support casters and additional casters (a), (b), so that driving tire gets little radial load. Driving tire is pushed by a spring to touch the handle and get adequate friction force.

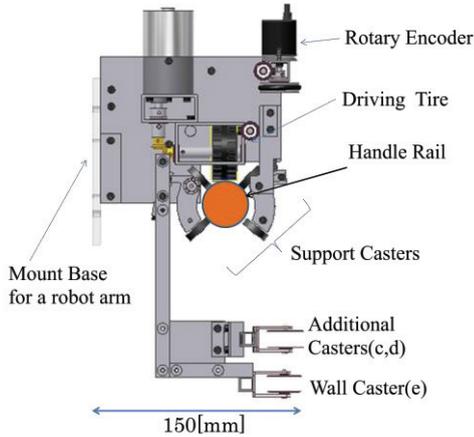


Fig. 6 Side view (Inner Structure)

### 3.2 Installation to Handle

Figure 7 illustrates the installation to the handle. The plates which have support casters (c), (d), (e), (f) are movable. When the platform is installed / uninstalled, the plates open and release the handle as (1). When the platform is driving or working, the plates fasten the handle. The driving tires are pushed to the handle by springs to get required friction force.

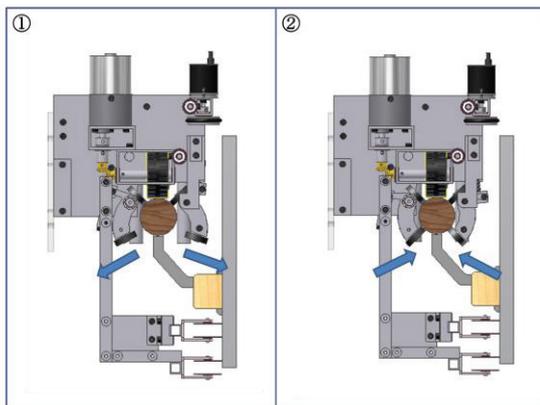


Fig. 7 Installation to handle

### 3.3 Control System

The robot system is controlled by a microcomputer for acquisition of sensor data and generation of motor drive signals (Fig. 8). A Renesas RX621 microcomputer is exploited as a main computer and it can communicate PC via ZigBee wireless connection. The system includes rotary encoder for measurement of the moving distance and battery.

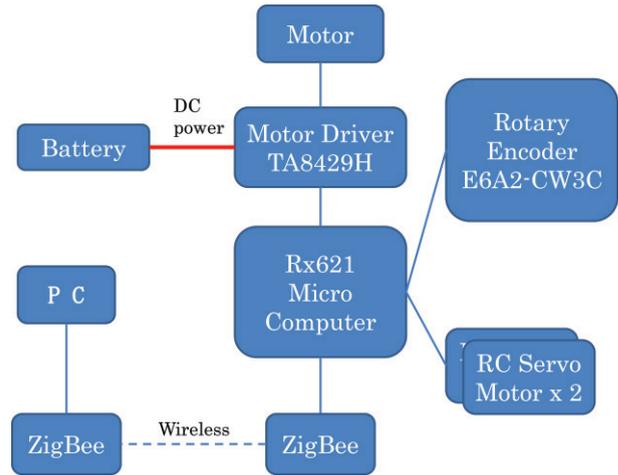


Fig. 8 Control system

### 3.4 Vertical Curve

There are actively controlled two arms with casters (a), (b) to follow the vertical curve. They guide the platform along the vertically curved rail. The arms are controlled to fit the vertical curve.

Figure 9 shows the adaptation to vertical curve. When one of the arms reaches the point where the bend begins, the arm link (a) or (b) that is on the point is rotated (1-2). When the driving tire is on the point, the rotated arm link is rotated to original angle again and another side arm link is rotated to fit the handle (3-4).

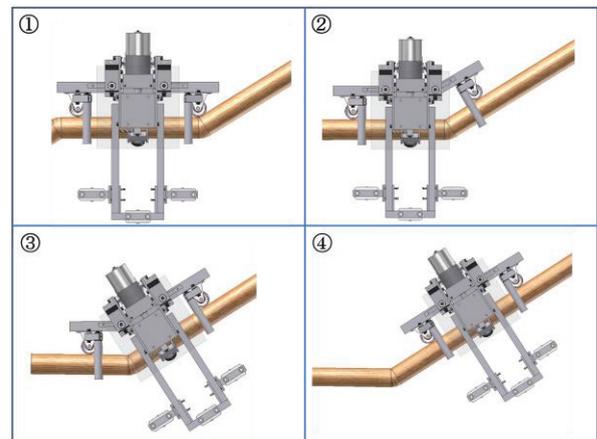


Fig. 9 Vertical curve (side view)

### 3.5 Horizontal Curve

There are casters (c), (d) to adapt the horizontal curve to follow the handle, and keep the distance from the wall constant. With the pipes in Fig. 5, the platform follow the perpendicular curved wall and handle without running off the caster (a), (b) from the handle.

Figure 10 shows the adaptation to horizontal curve. Additional casters (c), (d) are pushed to the wall so that casters (a), (b) and (c), (d) touch the wall and handle, respectively, even in horizontal curve. Thus the platform keeps its posture around x-axis.

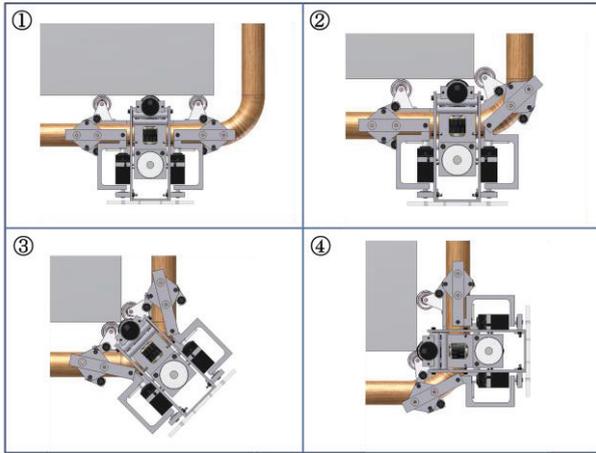


Fig. 10 Horizontal curve (top view)

## 4 Experiment

### 4.1 Basic Motion

The basic performance of the prototype was evaluated by experiments using a handle in Fig. 11. The handle is placed horizontal or inclined 30[deg] to test ascent or descent motion. The platform is loaded a payload or nothing. The maximum and minimum power consumption of the platform is measured from current and voltage (7.2[V]) of a DC power supply. The moving speed is measured from the time of moving 0.3[m].

The diameter of the handle is 34[mm]. The distance from wall to the center of the handle is 55[mm]. A robot arm which weights 1.05[kg] is used as the payload of the platform.



Fig. 11 Handle for experiments

Table 1 Power consumption

	Power consumption[W]	
	min	max
Horizontal w/o payload	1.44	1.80
30 deg ascent w/o payload	2.38	2.59
30 deg descent w/o payload	1.22	1.37
Horizontal w/ payload	1.73	2.09

Tables 1 and 2 show measured power consumption and measured speed respectively. Figures 12 and 13

show the pictures of horizontal traverse and 30[deg] ascension experiment.

Table 2 Moving speed

	speed [m/s]
Horizontal w/o payload	0.027
30 deg ascent w/o payload	0.015
30 deg descent w/o payload	0.029
Horizontal w/ payload	0.025



Fig. 12 Horizontal traverse



Fig. 13 30[deg] ascension

Without payload, the platform can move horizontally, ascend, and descend on the rail. With payload, the platform can move horizontally. Four support casters and additional casters (a), (b), (c) and (d) keep touching the handle or wall to distribute the load and the platform is moving stably.

When heavy payload is loaded, the springs of additional casters (h) is deformed and the platform is rotated around y-axis. Moving speed of the platform is changed depends on the load, without control.

### 4.2 Curve Motion

Traverse on vertical and horizontal curve is tested. The results are shown in Figs. 14 and 15. Both on vertical and horizontal curve the platform traverse on the rail stably using servo motors and casters.

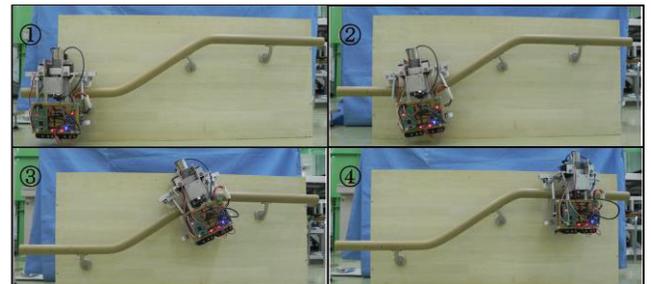
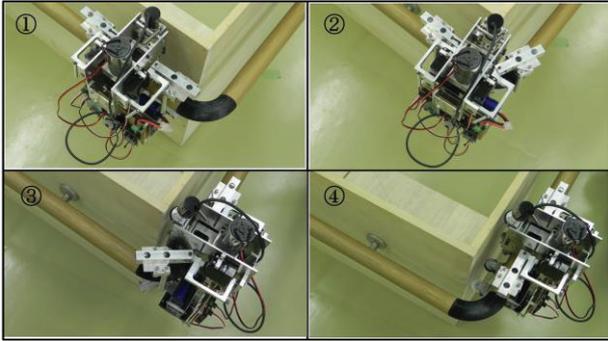


Fig.14 Vertical curve



**Fig. 15 Horizontal curve**

### 5 Conclusions

A simple and feasible indoor robot system for household use that consists of a wall mobile platform and robot arm was proposed. Exploiting the handle rail, the design of traversing mechanism was introduced and its basic performance was evaluated experimentally.

For future work, stabilization of the posture with robot arm and payloads sensor based motor control and curve traversing system will be developed.

### References

[1] Robocup@Home Homepage,

<http://www.robocupathome.org/>

- [2] Jones, J.L., "Robots at the tipping point: the road to iRobot Roomba", *Robotics & Automation Magazine*, Vol.13, Issue 1, pp.76-78, 2006.
- [3] Journee, M. and Chen, Q.X., "An Investigation into Improved Non-Contact Adhesion Mechanism Suitable for Wall Climbing Robotic Applications", *Proceedings of ICRA2011*, pp.4915-4920, 2011.
- [4] Suzuki, M. and Hirose, S., "Proposal of Swarm Type Wall Climbing Robot System "Anchor Climber" and Development of Adhering Mobile Units", *Journal of Robotics Society Japan*, Vol.28, No.5, pp.614-623, 2010.
- [5] Mori, T., Sato, T., "Development of Robotic Room 1,2 and 3", *Journal of IEICE*, Vol.91, No.5, pp.402-410, 2008.
- [6] Fukui,R., Morishita, H. Mori,T., Sato, T., "HangBot: a Ceiling Mobile Robot with Robust Locomotion under a Large Payload (key mechanisms integration and performance experiments)", *Proceedings of ICRA2011*, pp.4601-4607, 2011.
- [7] ThyssenKrupp HP  
<http://kaidan-noboru.com/>

Received on December 30, 2013

Accepted on February 7, 2014