A Supplementary Automatic Door Device for Hybrid Support of Humans and Robots

Rui FUKUI, Keita KADOWAKI, Hiroshi NOGUCHI, Taketoshi MORI, and Tomomasa SATO

Intelligent Cooperative Systems Laboratory, the University of Tokyo
Eng. bldg. 2nd, Room 81C1. 7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan
http://www.ics.t.u-tokyo.ac.jp

Abstract. This paper describes the development of Automatic Door Device as a part of intelligent environment. This device, Robo-Door, can release home robots from door opening/closing task and serve for handicapped humans as well. The characteristics of the device are (a) easy installation via wheel actuation and (b) compatibility of automatic motion and human manual handling by clutch mechanism.

Key words: Service robot, Automatic door, Intelligent environment, Ubiquitous robot

1 Introduction

Recently, robots are hoped to provide services for humans in living spaces , and as a strategy, structured or intelligent environment is proposed by several research groups, where sensors and actuators are distributed [1–4]. For example, Tomokuni et al. developed a caster type actuator (Active caster), which can be easily attached to a piece of furniture [5]. In addition to the purpose of supporting humans, those intelligent environments can play a role of providing infrastructures for service robots and may promote rapid introduction of current robot systems into our living spaces.

As a part of such approaches, this paper describes the development of a device to open/close a door automatically (Robo-Door, Fig. 1). For home robots, door opening/closing is an essential task [6, 7]. However, it is not practicable for robots without arms (ex. Roomba) to operate a door by themselves. By installing a door actuating device, the environment improves those robots' performances. In addition, automatic opening/closing of a door is also helpful for humans with physical handicap, especially when they use wheel chairs.

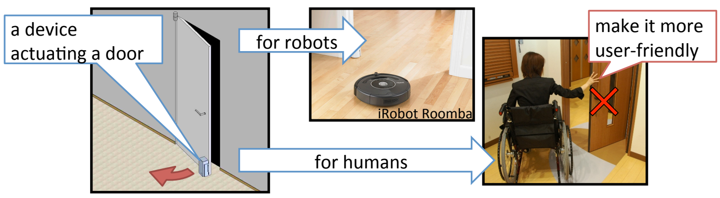

Fig. 1. Conceptual image of automatic door device

Therefore, the aim of our research is the development of a door opening/closing device which realizes (a) the support for physically handicapped persons and (b) the environmental arrangement for home robots.

The framework of this paper is as below; Implementation methodology for automatic opening/closing of a door and required specifications for the device are discussed in section 2. In section 3, design and implementation of the device are described. Experimental Results of the prototype are analyzed in Section 4, followed by conclusions and a discussion on future work in Section 5.

2 Required specifications and design of mechanisms

In this section, required specifications for Robo-Door and implementation methodology to satisfy the requirements are discussed.

2.1 Required specifications for automatic door opening/closing

Required specifications for Robo-Door are as below; (1) stable door operation, (2) ensuring safety and (3) low resistance for manual handling of a door. By definition, Robo-Door must open/close a door properly in order to enable humans and robots to go through. For ensuring safety, a function to stop operation is also required, ex. when a man/woman is caught in a door. In addition, manual usability of a door should be retained. This is because when the device is down (ex. electric outage) and if the door cannot be opened manually, the device may obstruct evacuation attempts. Moreover, it is stressful for most general users to wait for automatic opening/closing motion. Because not only the handicapped and robots but also healthy individuals use the same door, low resistance for manual operation is necessary.

Besides the described above, Robo-Door should solve a problem of doorknobs. It is enough, however, to just install a knob which can be unlocked by applying a certain extent of force, for example. This paper is discussed based on an assumption that such a doorknob has already been installed.

2.2 Methodology to realize Robo-Door

To satisfy the requirements described above, various methods can be listed. In Section 2.2, the way to realize automatic opening/closing of a door is considered especially focusing on (1) installation to an existing living environment and (2) co-existing of humans and robots.

Consideration of door automatizing methodology First of all, there are two schemes in order to realize automatic opening/closing of a door; (a) installation of a device to an existing door and (b) exchange of a door with easily automated one (ex. slide type, folding type and roller blind type). Fig. 2 shows the advantages and disadvantages of each scheme.

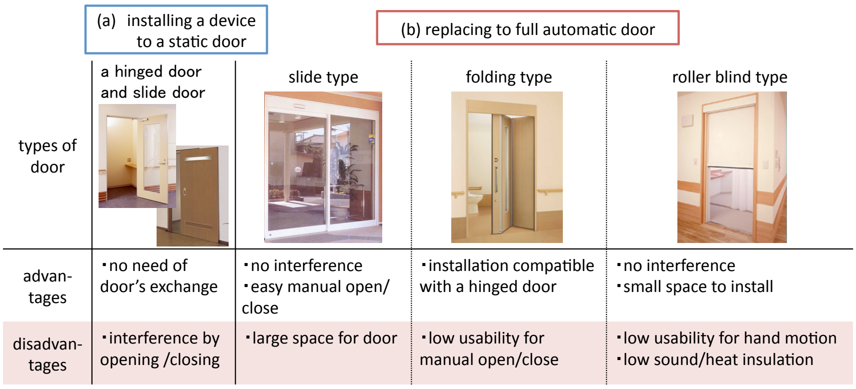

Fig. 2. Comparison of two methods, installing a special device or exchange of a door

In the case of equipping a device, it is needless to exchange a door of course. Considering installation to an existing environment, this is a big advantage. As an disadvantage, interference with passersby or other objects could happen especially if the door is hinged type.

On the other hand, each alternative candidate has some advantages and disadvantages shown in the right side of Fig. 2. Their advantages, especially no interference of slide and roller blind types, are attractive. But in addition to the disadvantages depicted in Fig. 2, they have a common problem of the exchange cost. In the case of new buildings suited to the handicapped or installation of robots, these doors might be installed at the initial stage. Considering installation to an existing environment, however, a costly approach is not likely to be accepted.

As shown above, (b) exchange of a door does not exceed (a) installation of a device, taking the cost and other disadvantages into consideration. Therefore, it is valid to automatize a door by installing a new device, Robo-Door.

Consideration of door actuation type Some supplementary automatic door devices have been produced (Fig. 3)[8, 9]. These commercial products adopt mechanical links to actuate a door. One advantage of this method is that the device does not interfere with human's living space. Moreover, it is easy to control because the degree of motor's rotation corresponds with the state of a door. However, most of these products need a high power motor and fabrication for installation, ex. punching on a wall. In addition to mechanical links, wires, wheels and magnetic force (like linear motors) can be listed for actuation candidates.

Fig. 3. Commercial products which opens/closes a door automatically by mechanical links

From these candidates, Robo-Door selects a method of actuation by a wheel. One advantage of actuation by a wheel is simplicity of its mechanism. Moreover, it could be installed to both hinged and slide doors by changing the direction of the device. Additionally, as described below, the equipping method to a door is taken into account for realizing installation without fabrication. In the case of installing a new system or device into human living environment, easy installation is one of the important factors. Furthermore, Robo-Door starts operation when it receives a command by wireless communication, therefore an user is supposed to carry a remote controller.

Analysis of functions required for door actuation by a wheel Robo-Door needs following 5 functions; (1) **Detection of collision**; Considering automation of a door, the device must ensure safety. Therefore, if humans, robots and other objects collide with a door, Robo-Door must detect the collision and stop immediately. (2) **Reduction of resistance in manual operation**; As described in Section 2.1, Robo-Door should not interrupt manual opening/closing. (3) **Easy installation**; For reduction of the installation cost, Robo-Door should be equipped with as little fabrication as possible. (4) **Sufficient door driving force**; One unique problem of the wheel actuation is that a floor state have influence on the device's performance. A floor of living space might be waving slightly, and the friction coefficient varies according to the material of the floor. To avoid slipping, it is essential to press the wheel to the floor. (5) **Recognition of door state**; One more problem is state recognition of a door. Just measuring rotation numbers of a wheel or a motor lacks accuracy, because a slip between the wheel and the floor, though it might be a little, causes error of the door position estimation.

3 Design and implementation of mechanism

Based on the discussion in the former section, design and implementation for satisfying the required specifications are described in this section. First, the whole structure of Robo-Door is depicted in Fig. 4. It consists of 3 units, (1) driving unit, (2) fixing unit and (3) slider guide unit.

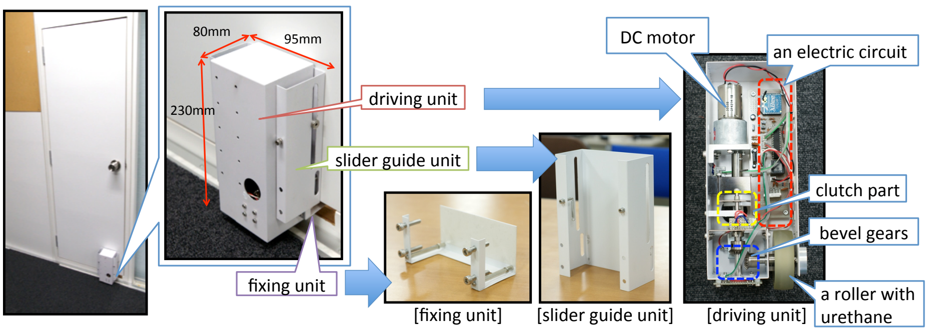

Fig. 4. Whole structure of Robo-Door

3.1 Collision detecting function by a current sensor

Robo-Door is supposed to stop its motion rapidly if the door bumps into humans or robots. Then, Robo-Door detects collision by measuring motor current, which increases as the load of the motor rises up. The current sensor installed in our prototype is "HPS-3-AS" produced by U_RD.

3.2 Resistance reduction function by a pin clutch mechanism

In order to reduce resistance in manual opening/closing of a door, a clutch mechanism is installed into the driving unit as shown in Fig. 5. Upper side of the two pins is shifted down by a DC solenoid, and mating of the two pins achieves transmission of power from the motor to the wheel. Normally, the upper pin is pushed up by springs. Using photo interrupters, it is ensured that the two pins do not interfere with each other when the clutch makes connected.

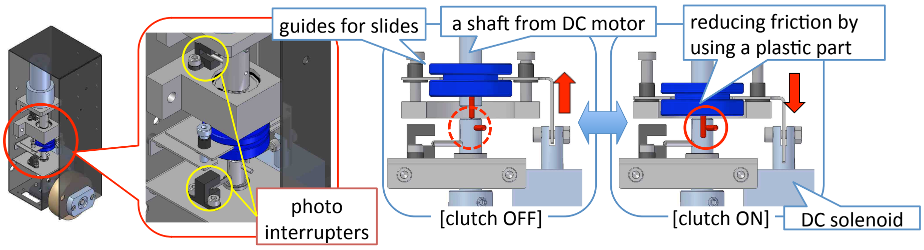

Fig. 5. Detailed description of the clutch mechanism

3.3 Door state recognition function by magnets and hall sensors

Recognition of the door state is realized by magnets placed on the floor and hall effect ICs equipped on the down side of the driving unit(Fig. 6). The sensor, DN6852 produced by Panasonic, has binary output according to increase/decrease of one way magnetic field. The distance between the sensors and magnets is about 2 [mm]. As shown in Fig. 6, two sensors are equipped side by side. By combining the sensors' outputs, Robo-Door distinguishes four different door state; fully open, fully close, on the magnet's point and the other. $10 \times 20 \times 1$ [mm] neodymium magnets are used in our prototype.

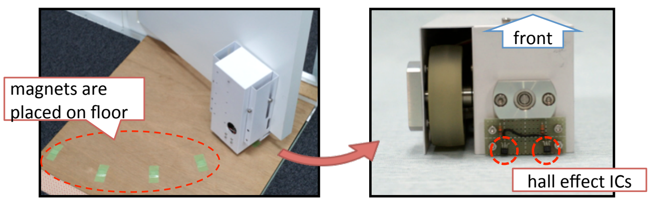

Fig. 6. Magnets and hall-effect ICs for door's position detection

3.4 Easy installation function by segmented structures

To make installation work as easy as possible, Robo-Door adopts a fixing method without fabrication like punching on a door (Fig. 7, left). Fixing is achieved by (1) clipping the bottom of a door in between the fixing and slider guide units, (2) clamping the slider guide unit against a door and (3) assembling the driving unit on the slider guide unit.

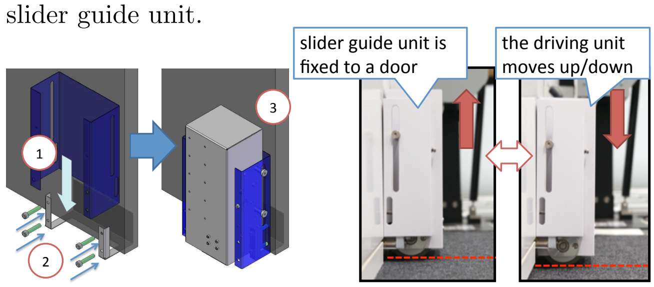

Fig. 7. (Left) Fixing the unit to the door without a punch, (Right) Slide mechanisum for driving force optimization

3.5 Driving force optimization function by a slide mechanism

As described in section 2.2, the condition of a floor might cause a problem in the case of wheel actuation. Avoiding slip, the driving unit can move up-down along with the channels of the slider guide unit. To get enough driving force, in addition, the driving unit is pulled down to the floor by springs equipped between the slider guide and driving units (Fig. 7, right). This function also provides an advantage that it is needles to adjust the placement appropriately to the gap between a floor and the bottom of a door, though the gap varies according to installation places.

4 Performance evaluation experiments

To evaluate the performance of a prototype Robo-Door, two experiments are carried out; (1) examining automatic opening/closing motion of a door and (2) verifying collision detection. The detail of the experiments are described below.

4.1 Automatic door operation experiment

[Condition] The prototype of Robo-Door is equipped to a room door and opens/closes the door according to a command from a wireless communication device (Digi international, XBee). Actuation of the door is tried on three kinds of floor: wood, carpet and cushion floor. In this experiment, the magnets for recognition of door's state are installed only on the wood floor.
[Result] The snapshots of the experiment on the wood floor are shown in Fig. 8 (upper), and the results on the carpet and the cushion floor are depicted in Fig. 8 (lower). As to these three types of floor, Robo-Door actuated the door successfully.

Fig. 8. Sequential snapshots of automatic door operation experiment

[Discussion] On each type of typical floors, automatic operation of the door by wheel was achieved without problems. Thus, the feasibility of Robo-Door was confirmed. In this experiment, magnets were temporarily fixed with tapes on the floor. The arrangement of the magnets should be modified for real applications.

4.2 Collision detection experiment

[Condition] In this experiment, Robo-Door actuates a door and collides with an object while its operation. A load cell (”LM10KA” produced by KYOWA Sensor System Solutions) and a data logger (”NR-600” produced by KEYENCE) are used to measure the collision force (Fig. 9). Running distances before the collision are 200 [mm] and 400 [mm], and the data is measured three times at each setting.

Fig. 9. Snapshot of collision detection experiment

[Result] The results of the collision detection experiment is shown in Fig. 10. The left side of Fig. 10 indicates the maximum applied force and continuous time during which over 10 [N] force was applied in each measurement. The right side of Fig. 10 is sequential force graph of the second trial in distance 400 [mm].

distance	trial	maximum force [N]	applied over 10N [ms]
	1	40.86	111
200 [mm]	2	34.01	86
	3	39.31	72
	1	25.22	350
400 [mm]	2	39.75	442
	3	24.47	684

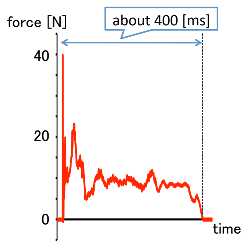

Fig. 10. the experimental result of collision detection

[Discussion] The experimental result shows that about 40 [N] force was applied to the object at the moment of impact. It is apparent from the graph, however, that the maximum of applied force was just around a peak. Afterward, lower than 20 [N] was applied continuously for some 100 [ms], and then Robo-Door stopped its motion by detecting collision. An impact energy corresponds to defined by multiplication of a force and its applied time. Therefore, the impact energy by collision is not serious. Consequently, it is demonstrated that collision detection function of Robo-Door using a current sensor has enough performance to ensure safety.

5 Conclusion

In this paper, we develop a device Robo-Door, which opens/closes a door automatically in living spaces. The purpose of Robo-Door is both daily life support for the handicapped and arrangement of intelligent environment for service robots. The main features of Robo-Door are (1) actuation by a wheel, (2) low resistance for manual operation and (3) easy installation into existing environment. It is shown by experiments that Robo-Door achieves opening/closing operation on various kinds of floor and has enough safety against collision with humans and robots.

As a future work, it is urgent to establish the way to arrange magnets properly on a floor for stable recognition of the door state. In addition, Robo-Door now can be equipped only to a hinged door. Therefore, design modification for installing into a slide door is also required.

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