The 8th TSME International Conference on Mechanical Engineering
12-15 December 2017
Bangkok, Thailand

DRC0003

Development of a standing up mechanism during falling down for small size home robots

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Abstract. Functions such as support, dialogue, and guidance with human beings are expected for home robots. However, there arise problems concerning hugging on the home robot and falling down of the home robot accompanying it. This paper develops a standing up mechanism during falling down as a home robot function capable of smooth service.

1. Introduction

Development and introduction of service robots are currently drawing much attention to open the 2020 Olympic and Paralympic Games in Tokyo, Japan [1]. For the service robots, functions of support, dialogue, guidance, and hospitality for human beings are expected, while safely moving in coexistence environments of the human being and service robot, such as home environments, commercial facilities, public facilities or the like [2, 3]. In particular, the service robot has the rapid development of Artificial Intelligence (AI) in recent years [4]. The dialogue and guidance of the human being with the service robot are enabled by speech recognition using AI. And furthermore, the recognition of environments and characters is enabled by image processing. As implemented technologies, there are communication by conversation as Apple’s Siri and Softbank Pepper [5, 6]. Furthermore, it is also possible to ask questions and make decisions as IBM Watson [7]. The communication technology with the human being by AI for the service robot is particularly remarkable with respect to software development and makes specialty areas of AI. The possibility of the communication technology between the human being and the service robot is expected [8]. On the other hand, service robots of various designs, unlike industrial robot arms, have been developed with respect to the hardware serving as main robot bodies [9]. However, the hardware of the service robot has not been narrowed down to a versatile platform. Some of the service robots are not taken into consideration, especially regarding safety aspects.

Here, we consider the case where the service robot is used as a home robot for a home environment. There is no need to select a powerful robot arm for carrying a heavy load or a moving mechanism with a high load mass for the home robot that performs dialogue and guidance to the human being. Therefore, the home robot is possible to reduce the weight of a robot body. Furthermore, as a design shape of the robot body at the home robot, the projected area on the moving plane tends to become smaller than the height of the robot body. The small projected area of the robot body gives the easy viewpoint of movements in obstacle avoidance. Because of this weight reduction and design shape of the robot body, the home robot has a problem that falling down easily occurs. The problem of falling down at the home robot is behind in the development of hardware, compared with the development of software at the communication technology by AI. For example, falling down of the robot body is caused by hugging on the home robot by a child and falling down accompanying it [10]. An inverted pendulum type mobile robot can cope with a certain power of external force [11]. However, it is difficult to prevent falling down by hugging on the robot body by the child in reality. In the worst case, there is a danger that a finger or the like will be caught in the robot arm by touching the robot body at the time of falling down. Carpets and magazines placed on the floor in the home environment also become obstacles in home robot movement. The home robot movement has uneven floor and obstacle avoidance problems by the obstacle. The possibility of falling down is increased in moving at the home robot by these problems. In the case of the home robot such as watching an old person, there is concern that the service will be stopped by falling down. These falling down problems of the robot body are to be solved in order to put into practical use of the home robot for the home environment.

In this paper, a standing up mechanism for the home robot is developed for falling down of the robot body. The standing up mechanism specially focuses on a mobile type home robot during falling down of the robot body. Design, development, and verification experiment by a developed home robot with the standing up mechanism are shown in this paper. The developed home robot with the standing up mechanism shows its effectiveness of practical application for falling down on the home environment.

2. Design and Development of the Home Robot

2.1. Small size home robot design

A design for the home robot is a mobile type home robot. A moving mechanism of the mobile type home robot is particularly a wheel type in this paper. The wheel type of mobile robot has simple control, efficient energy use, and accurate movement [12]. The wheel type of mobile robot also reduces production costs in comparison with a humanoid type of mobile robot, because of the number of driving motors.

The size of the designed home robot is a cylinder shape with a diameter of about 300 mm and a height of about 300 mm. The designed home robot is a small size for human beings, especially children. The size of the designed home robot does not give a sense of oppression to a little child, and sufficient mobility ability can be expected, when the home robot is used in a narrow home environment with obstacles, such as chair, table or the like [13]. The wheel type of mobile robot uses a special type driving wheel. The designed home robot can work omni-directional movement by using the special type driving wheel in the narrow home environment.

2.2. Small size home robot development

The wheel type of mobile robot equipped with a standing up mechanism is prototyped based on the above design as the home robot. An overall view of a developed home robot is shown in figure 1. The outside appearance of the developed home robot is a cylindrical shape. The developed home robot has the maximum diameter of 275 mm and the height of 305 mm when driving. The material of mechanical parts is mainly an aluminum alloy. The developed home robot is the weight of 1.7 kg. A robot body of the developed home robot uses the styrene foam in consideration of safety and weight reduction.

A folding up type of moving mechanism built in the developed home robot is shown in figure 2. The folding up type of moving mechanism is used as both the moving and the standing up. The standing up mechanism is given by the folding up type of moving mechanism with special type driving wheels, a circular shape of the lower part of the robot body and the position of the center of gravity (CG) of the developed home robot. A theory of the standing up mechanism is explained in detail in the next section. Three driving wheel legs of the moving mechanism have severally two servo motors (KRS4034HV: Kondo Kagaku Co., Ltd.) as shown in figure 2(*a*). One servo motor gives an independent joint for the folding up movement of a driving wheel leg, and the other servo motor drives

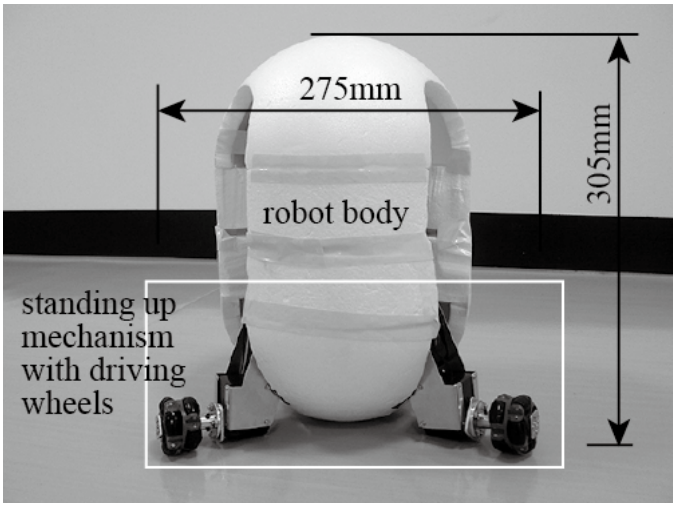
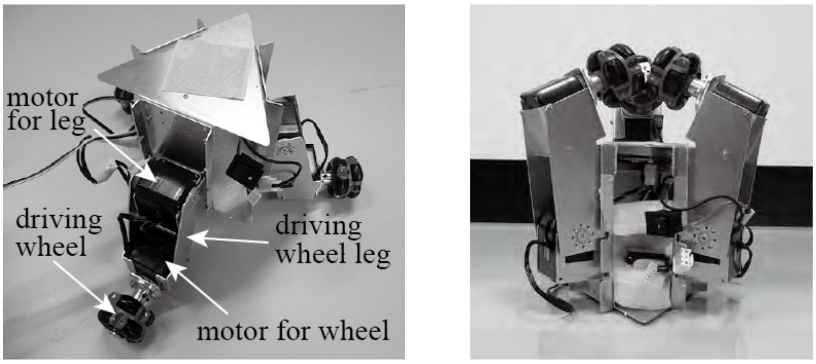


Figure 1. A developed home robot equipped with the standing up mechanism during falling down.



(a) (b)

Figure 2. A folding up type of moving mechanism built in the developed home robot.

the driving wheel. The driving wheel legs fold up during falling down of the developed home robot as shown in figure 2(*b*).

2.3. Details of the folding up type of moving mechanism and the theory of standing up

A ground plan of the folding up type of moving mechanism is shown in figure 3. Three special type driving wheels with free rollers are used for driving wheels. These special type driving wheels are each 120 degrees apart as shown in figure 3. The special type driving wheel gives the omni-directional moving mechanism for the developed home robot. A front view of a cross section A-A as shown in figure 3 is shown in figure 4. The structure of the folding up type of moving mechanism is detailed in figure 4. Motor control is performed by a control board (RCB-4HV: Kondo Kagaku Co., Ltd.) and gyro sensor (KRG-4: Kondo Kagaku Co., Ltd.) loaded on the moving mechanism, and a battery for power supply is also built in the moving mechanism as shown in figure 4. The motor for the leg gives the folding up and taking out movements of the driving wheel leg, and the motor for wheel drives the driving wheel.

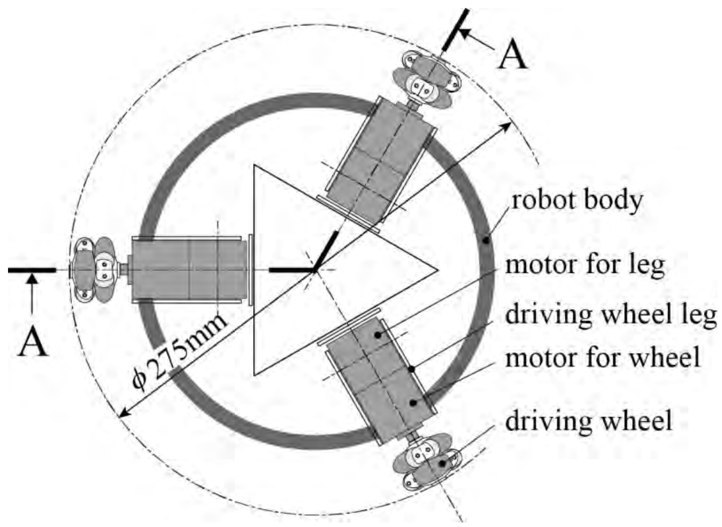


Figure 3. A ground plan of the folding up type of moving mechanism.

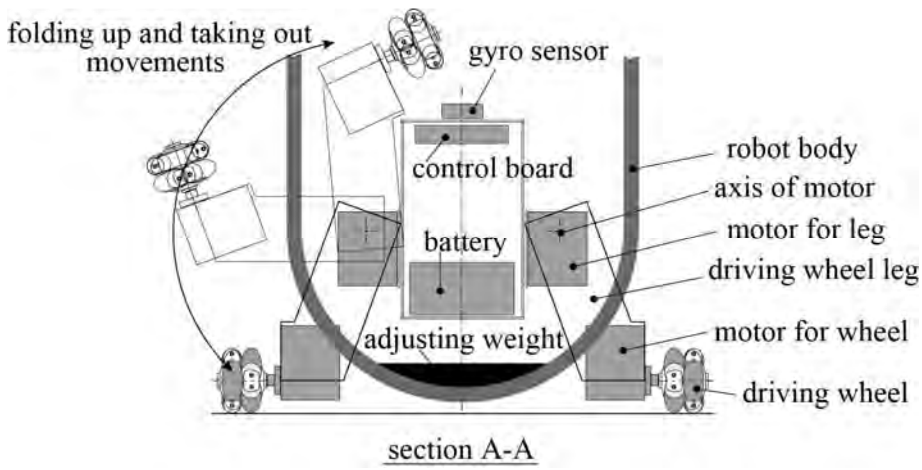
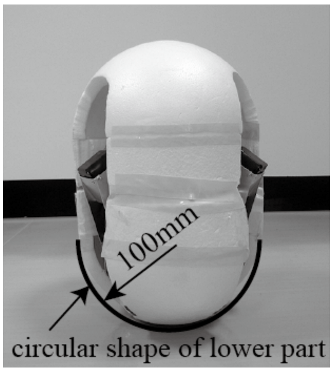
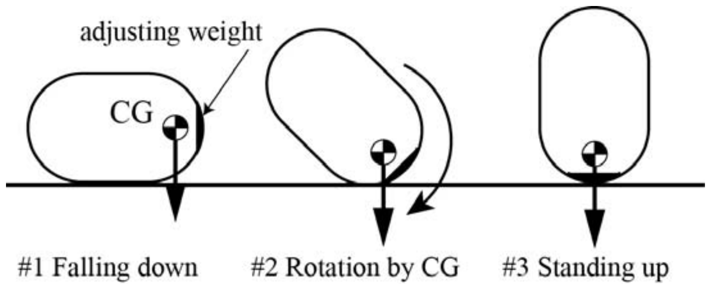


Figure 4. A front view of the folding up type of moving mechanism.

A weight for adjusting the position of the CG of the developed home robot is attached to the lower part of the robot body as shown in figure 4. The robot body of the developed home robot is possible to independently stand up like an Okiagari-Koboshi (Traditional self-righting DARUMA Doll in Japan) as shown in figure 5(*a*). The standing up motion of the robot body is given by the position of the CG of the developed home robot using the adjusting weight and the circular shape of the lower part of the robot body when the driving wheel legs fold up as shown in figure 5(a-*b*). The position of the CG must be within the circular shape of the lower part of the robot body because of the theory of independently standing up like the Okiagari-Koboshi. The radius of the circular shape of the lower part is 100 mm at the robot body as shown in figure 5(*a*). The adjusting weight for the position of the CG is 0.7 kg in the developed home robot. The adjusting weight of 0.7 kg is included in the developed home robot weight of 1.7 kg.





(*a*) (*b*)

Figure 5. The independently standing up motion of the developed home robot.

2.4. Control of autonomous standing up transformation

A desired posture of the developed home robot is usually a standing posture. A block diagram for standing up motion control is shown in figure 6. In figure 6, $\boldsymbol{P}_d$ is a desired posture, $\boldsymbol{P}$ is an actual posture. The standing posture of the robot body is controlled as feedback control system by using the gyro sensor. As the strategy of the standing up motion, the gyro sensor (KRG-4) loaded into the developed home robot detects falling down of the robot body when the developed home robot falls because of disturbance. Three motors of the driving wheel legs are controlled by the control board (RCB-4HV). The driving wheel legs fold up on the inside of robot body as shown in figure 5(*a*), and the posture of the robot body returns to the standing posture by the CG of the developed home robot as shown in figure 5(*b*). The standing up motion of the robot body is given by the position of the CG of the developed home robot using the adjusting weight and the circular shape of the lower part of the robot body. The developed home robot becomes possible to move again by taking out the driving wheel legs.

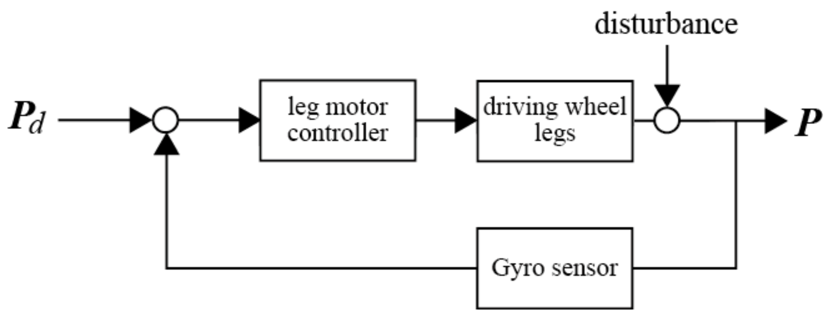


Figure 6. Feedback control system of the driving wheel legs by using the gyro sensor.

3. Experiments of falling down and standing up motions

An experiment of the standing up motion during falling down is given in order to verify the effectiveness of the developed home robot with the standing up mechanism. As the experimental conditions, the workspace for the movement of the developed home robot is a flat environment like home, and an external force for falling down is given as a disturbance by the hand of the human being. For ease of control, the three motors of the driving wheel legs are also controlled with the same holding up movement in the experiment.

An experimental result of autonomous standing up transformation is shown in figure 7(*a*-*i*). The developed home robot moves in the direction of the arrow as shown in figure 7(*a*-*b*). In figure 7(*c*-*d*), falling down of the developed home robot is given by the external force in the direction of the arrow. The developed home robot detects falling down by the gyro sensor, and three driving wheel legs fold up on the inside of robot body as shown in figure 7(*e*-*f*). The strategy of the standing up motion control is shown in section 2.4. The posture of the robot body returns to the standing posture, like the Okiagari-Koboshi. The developed home robot becomes possible to move again by taking out the driving wheel legs as shown in figure 7(*g*-*i*). As experimental results by the disturbance from various directions, it was confirmed that the developed home robot can stand up at any time.

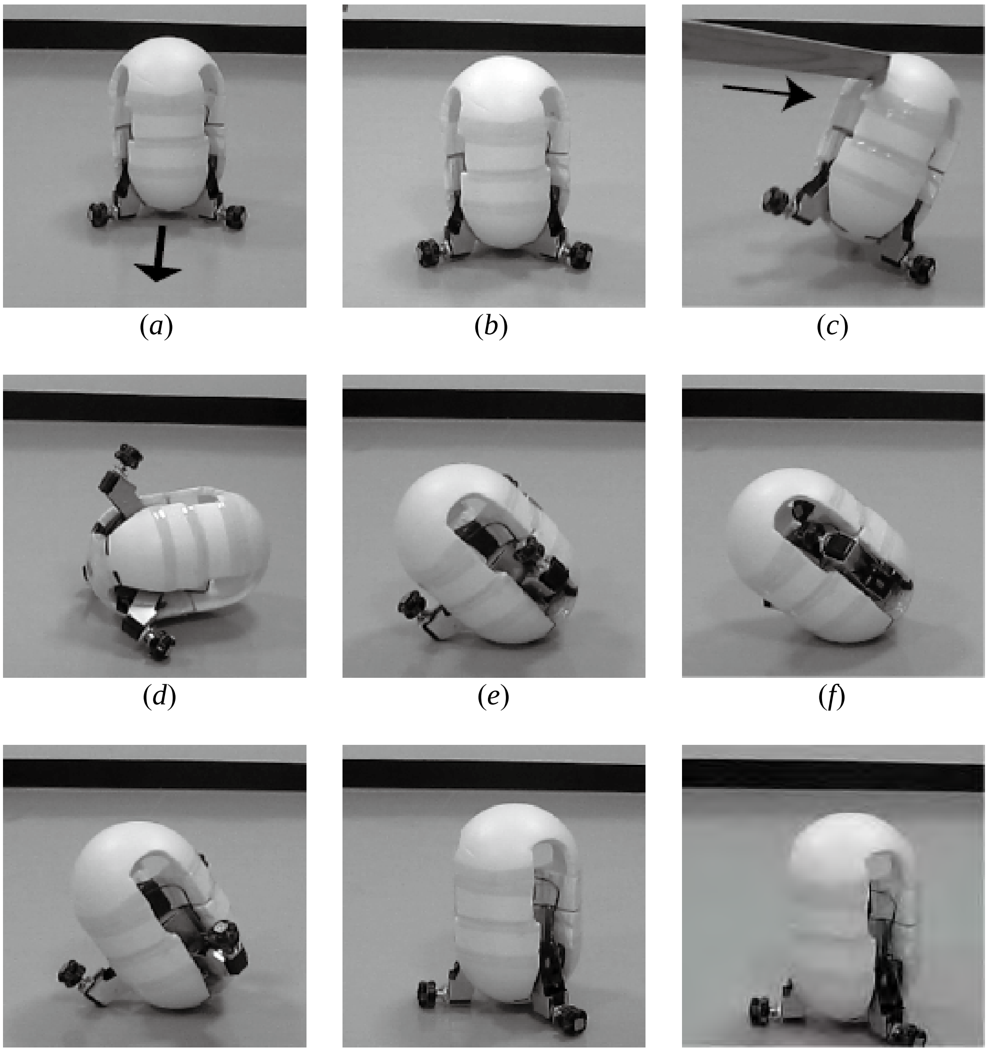


Figure 7. The experimental result during falling down by using the standing up mechanism of the developed home robot.

4. Conclusions

This paper has developed the standing up mechanism of the home robot for falling down of the robot body. The developed home robot verified the effectiveness of the standing up mechanism during falling down on the home environment.

In the future work, we plan to install a touch panel capable of presenting visual information with human beings as the home robot. Service functions such as voice recognition and image recognition are included to the touch panel. We will also make improvements on the safety of the standing up mechanism. In addition, we think that it is necessary to analyze the dynamic motion of the developed home robot during the standing up motion.

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