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Development of a mechanical safety device for service robots

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Abstract: In this paper, we present a new safety device to improve the safety of service robots for humans. The safety device consists of only mechanical components without actuators, controllers and batteries. The safety device is attached to each drive-shaft of a robot and locks the drive-shaft after detecting an unexpected robot motion on the basis of the drive-shaft's angular velocity. First, we present the design concept of the safety device. Second, we explain the mechanism of the safety device. Third, we show the developed safety device. Fourth, we experiment by using the developed safety device. Finally, from the experimental results, we discuss the usefulness of the safety device.

Keywords: Human-machine cooperative systems, Human-welfare robotics, Robotics, Safety device, Service robot

1 INTRODUCTION

Recently, there has been a growing interest in service robots which can support human daily activities. In industrial robots, safety of humans is implemented by isolating the robots from humans. However, in service robots, it is not possible to isolate the robots from humans because the robots work within human environments. Therefore, human safety becomes one of the most important issues in service robotics [1]-[4]. In this paper, we present a new safety device to improve human safety. The safety device consists of only mechanical components without actuators, controllers and batteries. The safety device is attached to each drive-shaft of a robot and locks the drive-shaft after detecting an unexpected robot motion on the basis of the drive-shaft's angular velocity. First, we present the design concept of the safety device. Second, we explain the mechanism of the safety device. Third, we show the developed safety device. Fourth, we experiment by using the developed safety device. Finally, from the experimental results, we discuss the usefulness of the safety device.

2 MECHANICAL SAFETY DEVICE

2.1 Characteristics of the Safety Device

The characteristics of the safety device are shown as follows:

(1) If the angular velocity of a drive-shaft (hereinafter referred to as "shaft") exceeds a preset threshold level, then the safety device for the shaft is activated. We call the preset threshold level "detection velocity level".

(2) The detection velocity level is adjustable.

(3) After detecting the unexpected robot motion on the basis of the angular velocity, the safety device switches all motors of the robot off.

(4) After switching off all motors, the safety device locks the shaft.

(5) The lock of the shaft is released by rotating the shaft in a direction opposite to the direction in which the safety device locks the shaft.

(6) The safety device consists of only passive components without actuators, controllers and batteries.

By the above characteristics (1), (3) and (4), we can expect that the safety device prevents high-speed collision between the robot and a human and reduces the collision force (see Fig.1 (i) and (ii)). Furthermore, by (2), we can adjust the detection velocity level according to the requirements for the given task. For example, when the

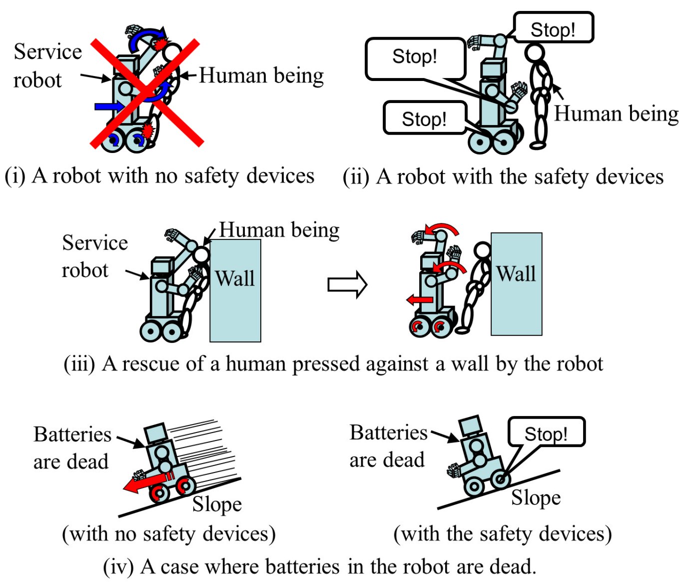

Fig.1 Characteristics of the safety device

robot is required to share workspace with humans in order to support humans, we can set the detection velocity level to low. When the robot is required to perform a high-speed task, we can set the detection velocity level to high and evacuate the robot's workspace. Additionally, by (5), if a human is pressed against a wall by the robot locked by the safety device, we can easily rescue the human by moving the robot in a direction opposite to the direction in which the human is pressed (see Fig.1(iii)). Finally, by (6), even if the batteries in the robot are dead, the safety device can act because it requires no power supply (see Fig.1(iv)).

2.2 Structure and Mechanism of the Safety Device

2.2.1 Structure

Fig.2 shows an example of robots equipped with the safety devices. As shown in Fig.2, the shaft of the robot arm is driven by the motor. In order to lock the shaft in clockwise and counterclockwise directions, two safety devices (one safety device for locking in the clockwise direction and another safety device for locking in the counterclockwise direction) are installed.

Fig.3 shows the structure of the safety device. Gear A, Plate B and Ratchet Wheel A are attached to the shaft of the robot arm. Claw B is attached to Plate B by Pin D. Guide Bar B attached to Claw B is inserted in Guide Hole B of Plate A. The shaft rotates Plate A via the torsion spring. One end of Linear Spring A is connected to Pin B attached to Plate C, and another end is connected to Pin A of Frame B. Plate C has Inner Teeth. Guide Bar A attached to Claw C is inserted to Guide Hole A of Plate C. Gear B meshes with Gear A. A rotary damper is connected to Gear B. Claw A is connected to the axis of the rotary damper. One end of Linear Spring B is connected to Claw A, and another end is connected to Frame A. Frame A is mounted on Frame B. Switch A which can interrupt electric power supply to all motors of the robot is installed at the position of being pressed by Pin C when Plate C is rotated. Fig.4 shows the details of Plate A. The ratchet teeth portion is connected to the plate portion via a spring.

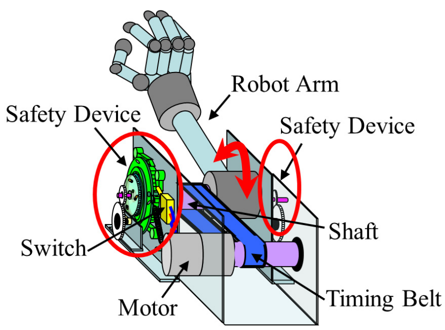

Fig.2 A robot arm with mechanical safety devices

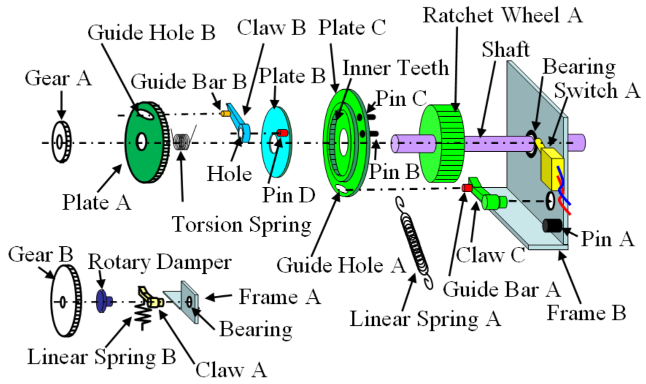

Fig.3 The structure of the mechanical safety device

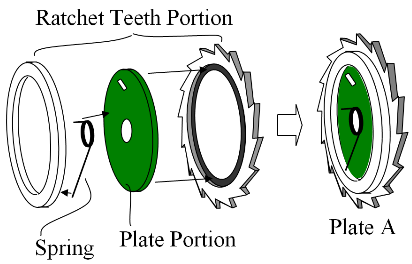

Fig.4 Details of Plate A

2.2.2 Mechanism

(1) Velocity-based detection mechanism

Fig.5 shows the mechanism which mechanically detects the unexpected robot motion on the basis of the angular velocity of the shaft. The damping torque by the rotary damper and the spring torque by Linear Spring B act on Claw A, when Gear B is rotated by Gear A. As the velocity of Gear A (shaft) increases, the damping torque increases. Claw A rotates by the torque difference between the damping torque and the spring torque, and locks Plate A, if the velocity of the shaft exceeds the detection velocity level. The detection velocity level is adjustable by changing the position where the end of Linear Spring B connected to Claw A is attached.

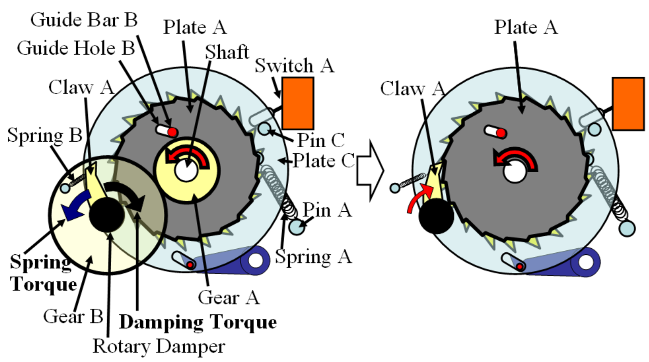

Fig.5 The velocity-based detection mechanism

(2) Shaft-lock mechanism

Fig. 6 shows the mechanism to mechanically lock the shaft. After Plate A was locked, Claw B slides along Guide Hole B of Plate A by the rotation of Plate B and contacts with the inner teeth of Plate C, as shown in Fig. 6(b). After contacting with the inner teeth, Claw B is hooked to the inner teeth and rotates Plate C (Fig. 6(c)). By the rotation of Plate C, Pin C switches off and Claw C moves along Guide Hole A (Fig. 6(d)). After that, Claw C meshes with Ratchet Wheel A and thus the shaft is locked.

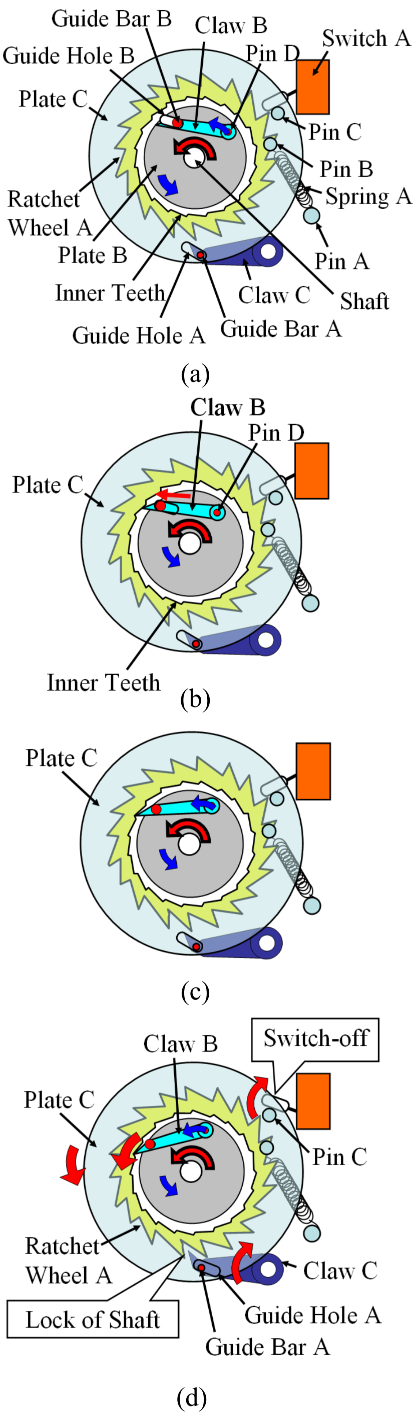

Fig. 6 The shaft-lock mechanism

After the shaft is locked, the damping torque acting on Claw A becomes zero. However, if the gravitational torque generated by the arm acts on the shaft in the direction where the safety device is locking (see Fig.7), the lock of the shaft is kept by meshing between Ratchet Wheel A and Claw C. The lock of the shaft is released by moving the arm in the inverse direction.

After the shaft is locked, if the gravitational torque acts in the inverse direction to that of Fig.7 and the velocity of the shaft exceeds the detection velocity level in the inverse direction, the shaft is locked by another safety device for the inverse direction. If the velocity of the shaft does not reach the detection velocity level, the arm slowly falls down and stops in a state of being suspended from the shaft.

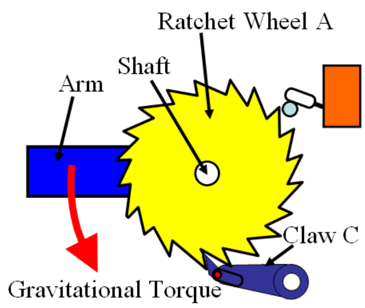

Fig.7 Lock of shaft

(3) Mechanism using three claws

In the above mechanism, in order to be meshed with Ratchet Wheel A and Claw C, it is necessary that the teeth number of Ratchet Wheel A equals the number of inner teeth of Plate C. It is preferred that the rotation angle of Claw B is as short as possible after Claw B contacts with the inner teeth of Plate C. As a method for shorting the rotation angle of Claw B, we can propose increasing the number of inner teeth on Plate C and the number of teeth on Ratchet Wheel A. However, there is a limitation on an increase in the number of inner teeth, because the safety device installed to robot is required to be as compact as possible.

In the following, we explain a mechanism using some claws. By using some claws, the mechanism provides the same advantage as when the teeth number is increased. Fig. 8 illustrates the mechanism in which three claws are used. Each claw is positioned as shown in Fig. 8(a). Lines 1, 2 and 3 trisect each tooth of the inner teeth. If Claw B_1 does not mesh with one of the teeth at the moment of contact, only with the movement of Claw B_2 by one third

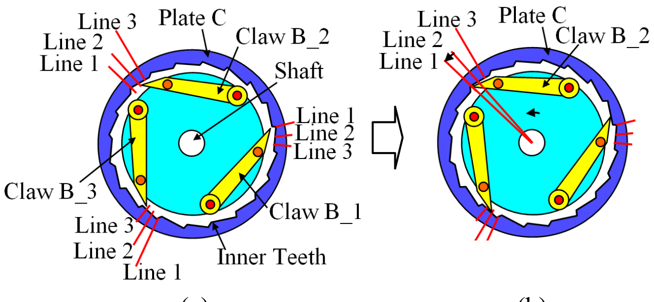

Fig.8 Three claws

of the tooth width, Claw B_2 meshes and rotates Plate C (Fig.8(b)). Note that, in this case, by using the Ratchet Wheel A having three times as many teeth as the inner teeth, Claw C is reliably meshed with the Ratchet Wheel A.

3 EXPERIMENT AND DISCUSSION

We developed the safety device using three claws' mechanism. We experimentally examined whether the shaft is stopped by the developed safety device after the angular velocity of the shaft exceeds the detection velocity level. Fig.9 shows the experimental setup. We attached some markers on the shaft and Claw A, then measured the positions of the markers by using a motion capture system (HAS-500, DITECT Corporation) while increasing the velocity of the shaft by the motor. The sampling frequency of the motion capture system was 200[Hz]. We experimented using a detection velocity level of 2.3 [rad/s]. The number of trials was 10. The angle of Claw A was approximately 0.21[rad] when Claw A locks Plate A.

Fig. 10 shows a typical example of the experimental results. Fig. 10 indicates that the shaft was stopped by the safety device after the angular velocity of the shaft exceeded the detection velocity level. The other results were approximately the same as this result.

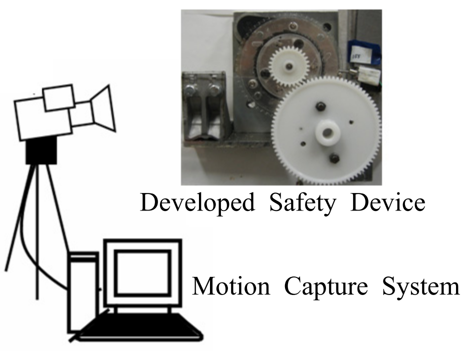

Fig.9 Experimental setup

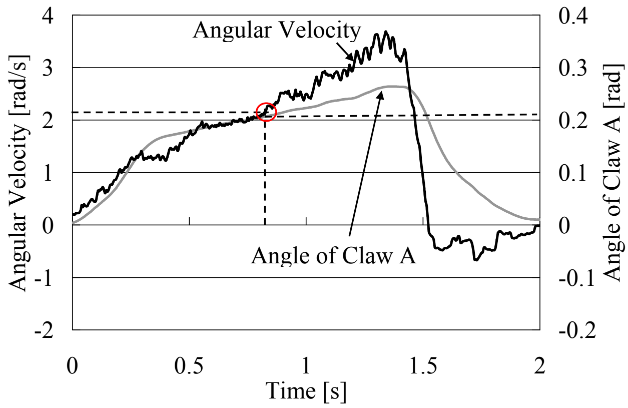

Fig.10 Experimental result

4 CONCLUSION

In this paper, we presented a new safety device to improve the safety of service robots for humans. Furthermore, we designed and developed the safety device. Finally, we experimentally examined the usefulness of the safety device.

ACKNOWLEDGMENT

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