Endtip Design for Stable Jumping Motion in Various Ground Conditions

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Abstract − A portable guard robot should be able to overcome relatively high obstacles to cope with different situations. To satisfy this requirement, a small jumping robot based on a conical spring and a variable length endtip based on a nut-screw mechanism, is proposed in this paper. If an obstacle obstructs the designated path, the robot jumps up from the ground to overcome it. However, the robot fails to jump in some cases because the jump is affected by several factors such as the endtip material and shape and the ground conditions. Various experiments demonstrate that the jump performance can be improved by selecting the appropriate endtip material and shape for different ground conditions.

Keywords − Jumping mechanism, Nut-screw mechanism, Conical spring, Clutch mechanism, Jumping robot.

1. Introduction

In recent years, security guards have been replaced by security robots due to significant advances in robot technology. The requirements for such security robots are low-cost, small-size, lightweight, high mobility, high durability, high reliability and etc. Among them, the high mobility is one of the most important features for a small guard robot since the places in which the robot operates are not determined. When the robot encounters an obstacle, the robot should pass by it or should overcome it to reach the destination.

Much research has been done to improve the mobility of small mobile robots. [1-6] Jumping is one of the good methods for the enhancement of mobility since it allows a robot to get to higher places quicker than other locomotion methods. Jumping ability can be provided by means of elastic energy, pneumatic energy and so on. Scout, a representative cylindrical type jumping robot, used the elastic energy of the leaf spring. [1] Various types of wheels were also developed to improve the mobility of a small robot. The "Mini-Whegs", a biologically inspired robot, used the four-bar linkage mechanism with an extension coil spring. [2] The structure was so simple, but high mobility was achieved. The "Leg-in-Rotor" using pneumatic energy showed good jumping performance [3]. Compared with other methods, the elastic energy of a spring has the advantages of being compact and lightweight.

In this paper, a small jumping robot based on a conical spring with a variable length endtip mechanism is proposed. When the path to the desired position is blocked by obstacles, the robot jumps up from the ground to overcome it. In accordance with the height of the obstacle, the jump force and jump angle are controlled by adjusting the length of the conical spring and endtip, respectively. Nevertheless, jumping sometimes fails since the jump ability is also affected by the materials and shapes of the endtips as well as the ground condition. To cope with this problem, this paper evaluates how the materials and shapes of the endtip affect jump performance. Three types of endtips made of steel, duralumin and urethane were fabricated to investigate the effects of the endtip material. Six different shapes of the endtips were also tried to investigate the effects of the endtip shape. A series of experiments on different ground conditions were conducted. It is shown that the jump ability in different ground conditions can be improved by replacing the endtip materials and endtip shapes.

2. Jumping Robot

2.1 Jumping Robot

The small-sized and lightweight guard robot equipped with the jumping mechanism is shown in Fig. 1. The robot consists of a body, two wheels and a jumping module. The wireless LAN camera mounted on the center of the robot provides the visual information to the operator. Some sensors such as a range sensor, an acceleration sensor and a gyro sensor installed on the robot body are used for autonomous control of the robot. The polycarbonate body and the cellasto wheel are advantageous to protect the inner parts such as electrical circuits against the impact force occurring when the robot lands. The MCU (DSP2808) with some motor driver ICs were used. The Bluetooth communication was adopted for remote control. The wheel diameter is 18cm and the length of robot is 30cm. The total weight of the robot is about 3kg.

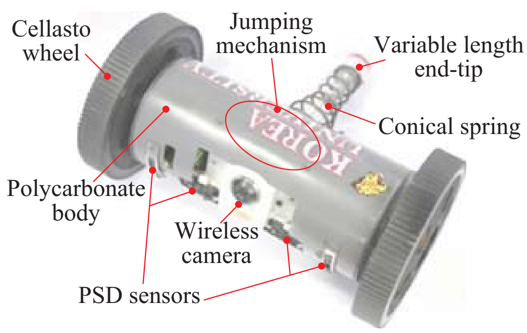

Fig. 1 Jumping robot based on conical spring.

2.2 Jumping mechanism

The jumping mechanism shown in Fig. 2 consists of a conical spring, a clutch mechanism and a variable length endtip. The conical spring is a nonlinear spring because it has different diameter at both sides. Therefore, the conical spring can be nested as it compresses, which leads to maximum compression. The clutch mechanism composed of a planetary gear train and a one-way clutch enables compression and decompression of the spring with a single motor by changing its direction of rotation.

The one-way clutch consisting of a ratchet, a pawl and a leaf spring is placed inside the carrier. The carrier is connected to the motor shaft through the bearing and thus is capable of rotating around the one-way clutch. Both the ratchet and the sun gear rotate CW due to the rotation of the jumping motor. The ratchet pushes the pawl, whereas the sun gear meshes with the planet gear. Then, the carrier rotates CW due to a small spring force from the resistance to rotation of the pawl. After the planet gear meshes with the winder gear, the torque of the motor is transmitted to the winder for the compressing of the conical spring through the sun gear, the planet gear and the wind gear. In this case, the spring force is smaller than the torque of the motor, thus the pawl allows the rotation of the ratchet.

On the other hand, if the motor rotates CCW, the ratchet and sun gear also rotate CCW. The rotation of the pawl in the CW direction is limited by the stopper, and the motor torque is directly transmitted to the carrier and thus the carrier rotates CCW. Consequently, the spring is released at once due to the disengagement of the winder gear and planet gear.

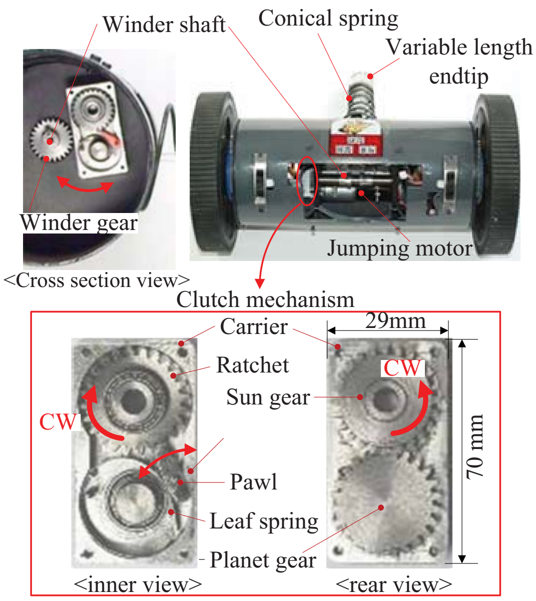

Fig. 2 Jumping mechanism.

2.3 Variable length endtip mechanism

As shown in Fig. 3, the variable length endtip consists of an endtip nut, endtip screw, endtip guide, pin and small endtip motor. Due to the nut-screw mechanism, the total length of the endtip changes as the motor rotates. The M8 screw and nut with a pitch length of 1.25 mm were used for the endtip mechanism, so the endtip nut moves 1.25mm along the axial direction for one revolution of the endtip motor.

By controlling both the compression length of the conical spring and the total length of the endtip, the robot adjusts the jump force and jump angle independently. Therefore, overcoming the obstacle can be achieved more stably by tuning the trajectory of jump motion in accordance with the obstacle height

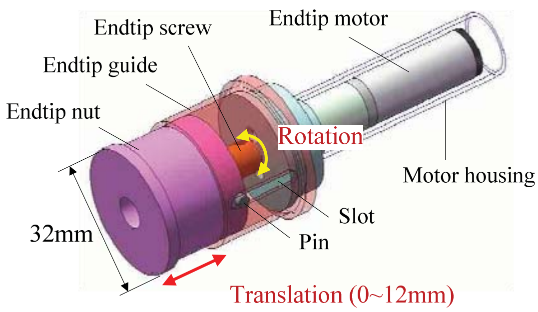

Fig. 3 Variable length endtip.

3. Endtip Design and Experiment

3.1 Endtip Design

To achieve a stable jump, sufficient friction force between the endtip and the ground is required. The friction force is usually generated from the coulomb force (e.g., dry friction), but it often occurs due to the plastic deformation when the endtip chops at the ground. Therefore, the jump ability is highly related to the materials and shapes of the endtip as well as the condition of the ground.

3.2 Effects of Materials

As shown in Fig. 4, three types of endtips were fabricated to investigate the effects of both endtip materials and the ground condition. They have identical shapes, so one can be easily replaced with each other.

Fig. 4 Three types of endtip nuts.

Jump tests on different ground materials (e.g., marble, laminated floor, veneer board) were conducted with three types of endtips. There are nine combinations of endtip materials and ground conditions and the experimental results are shown in Fig. 5. The height of the obstacle used in this experiment was 15 cm and the robot was controlled by a remote controller. The compression length of 135 mm and the jump angle of 60° were maintained for all experiments.

The steel endtip works well on the laminated floor and veneer board, but it does not work well on the marble ground. The robot equipped with the steel endtip jumped more than 20 cm and climbed the step. However, the steel endtip does not work on the marble ground because the slip between the steel endtip and the marble ground occurs as the robot starts to jump. Compared to the steel endtip, the duralumin endtip shows good jump performance for all types of grounds. It can jump more than 20 cm for all ground conditions. However, the edge of the endtip was easily unsharpened with repeated jump motion.

In contrast to the steel endtip, the urethane endtip works well only on the marble ground, whereas it shows poor jump performance on the laminated floor and veneer board. Therefore, the jump ability on different ground conditions can be improved by selecting the appropriate endtip materials.

I: Marble II: Laminated floor III: Veneer board

Fig. 5 Jumping tests on different grounds.

3.3 Effects of Shapes

To investigate the relationship between the jump ability and the endtip shape, six types of endtips shown in Fig. 6 were fabricated. These endtips were mainly divided into two groups. The first group- endtip *A*, *B* and *C*, features a different radius of curvature while the second group, endtip *D*, *E*, and *F* characterizes a different number of contact points.

As the radius of curvature of the endtip increases, stress concentration is distributed slightly near the contact point. The blunt of edge of the endtip is suppressed during the jumping motion even though the number of contact points is still one. The radiuses of curvature of endtip A, B and C were 16 mm, 40 mm, and 80 mm, respectively.

On the other hand, endtip D has two contact points at both ends and endtip E has three contact points at both ends and at the middle of the endtip. Endtip F has infinite number of the contact points, which means a linear contact. Compared to the contact points of the first group, the contact points of the second group are uniformly distributed at the edge of the endtip.

Fig. 6 Various types of endtip nuts.

Various experiments shown in Fig. 7 were conducted to evaluate the effects of the endtip shapes on jump performance. The jumping experiments were conducted 10 times for each endtip. The effect of the number of contact points of the endtip was investigated by comparing the experimental results of (a), (d) and (e). In addition, the effect of the radius of curvature of the endtip was examined from the results of (a), (b), (c) and (e).

It is noted that the maximum jump height was similar for all cases when the robot performed a stable jump, but the success rate of the jump motions was different. The robot with endtip A showed a stable jump for all 10 trials. As the radius of curvature increased, the success rate was almost the same except for the case of endtip F (i.e., infinite radius of curvature), which has the lowest success rate. Unexpectedly, endtip C showed the best jump performance, whereas endtip F showed the lowest success rate even though it looked as stable as ever among endtips. Therefore, that case was considered in more detail.

Assume that the coil spring is fixed at one side and the endtip is connected to the other side, as shown in Fig. 8(a). When the spring compresses, the total length of the spring decreases and the free end of the spring twists slightly, as shown in Fig. 8(b). As a result, the endtip rotates for an amount of θ_t, which is the twist angle of the endtip, while maintaining contact with the ground. If the circular endtip shown in Fig. 8(c) was installed, the center of the endtip moves vertically up by δ, which is proportional to the radius of curvature of the endtip. If the radius of curvature of the endtip is small, the twist of the endtip has no effect on the jump motion. However, if the radius of curvature is large, as shown in Fig. 8(d), the center of the endtip moves vertically up by Δ, which cannot be ignored. The jump angle of the robot decreases due to the increase of Δ and the endtip contacts with the ground unstably, as shown in Fig. 8(d). Therefore, the jump motion frequently fails because the endtip under such conditions could easily slip when the robot starts to jump.

	Endtip	Jump test	Success rate
A			100%
B			100%
C			100%
D			90%
E			70%
F			60%

A: R16 B: R40 C: R80

D: Double point E: Triple point F: Infinite point

Fig. 7 Jumping tests on different shapes of endtips.

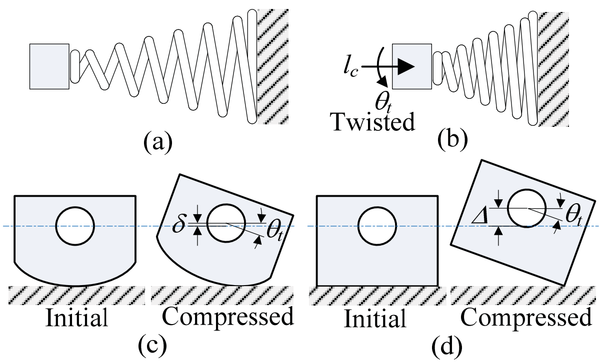

Fig. 8 Twisting of coil spring: (a) initial state of spring, (b) compressed state of spring, (c) circular endtip, and (d) rectangular endtip.

4. Conclusion

The jumping robot examined in this research consists of the jump mechanism based on a conical spring and the variable length endtip based on a screw-nut mechanism. The relationship between the jump ability and the endtip material and shape, and the ground condition were investigated. From this research, the following conclusions are drawn:

(1) The jumping robot equipped with the duralumin endtip can jump well on the marble, laminated floor, and veneer board.

(2) The jumping robot with the endtip with a radius of curvature of 80mm shows good jumping performance.

(3) As the number of contact points increases, the degree of wear of the endtip and the success rate of jumping decrease.

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