Development of Jumping Mechanism for a Portable Guard Robot

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Abstract

A guard robot should be small-sized and lightweight to increase its portability. In addition, it should be able to overcome relatively high obstacles to cope with different situations. A small two-wheeled robot capable of jumping can satisfy these requirements because the jumping robot can reach a high place more rapidly than other locomotion methods. This research proposes a small robot equipped with the jumping mechanism based on a conical spring. Both the clutch mechanism and conical spring are incorporated into the jumping mechanism. In the clutch mechanism, the spring can be compressed and released instantly by a single actuator together with a planetary gear train and a one-way clutch. The proposed jumping robot can overcome obstacles that are higher than its height. Various tests demonstrate the performance of the proposed guard robot.

1. Introduction

The use of various types of robots in security is increasingly important. These robots can replace security men in normal patrol in order to reduce labor costs. Furthermore, they can be used to prevent security men from directly investigating suspicious scenes. To satisfy the requirements for a guard robot, they should be small-sized and lightweight to increase its portability. In addition, it should be able to overcome a relatively high obstacle to cope with different situations.

To this end, a portable guard robot capable of jumping is proposed in this paper. This jumping robot can reach a higher place more quickly than other locomotion methods. In the design of the jumping robot, steering, jumping and shock-absorbing must be considered. The robot needs to control the jumping height and direction when it jumps. Of course, the robot needs the shock-absorbing capability to avoid the damage when it lands. The recovery function which means that the robot recovers its pose when the robot is overturned is also required.

There are many ways to provide the jumping ability, including the use of elastic energy, pneumatic energy, combustion energy and so on. Scout, the cylindrical jumping robot, used the leaf spring for jumping [2]. Its small size makes it portable. The “Leg-in-Rotor” used the cylinder with pneumatic energy [3]. The robot can run not only on the normal terrain at high speeds, but also on the rough terrain covered with the brick, wood and so on. The “Hopper” could jump very high using combustion energy [4]. From these previous researches, it follows that the jumping characteristics heavily depends on the source of energy. Compared with other methods, the elastic energy of a spring is one of the best ways to make a robot compact and lightweight.

In this paper, the jumping module based on a clutch mechanism and a conical spring was proposed. By using the clutch mechanism composed of a planetary gear train and a one-way clutch, it is possible to compress the conical spring and release it with a single motor by changing its rotational direction. A conical spring adopted in this robot is less likely to undergo buckling than a normal coil spring, which enables the maximum compression of the spring. This guard robot is controlled by remote control using the Bluetooth communication and the visual information taken by the built-in camera is delivered to the remote operator. Various experiments demonstrated that the jumping mechanism can improve the mobility of a small robot to overcome an obstacle or climb stairs.

2. Jumping Mechanism

The proposed guard robot uses the elastic energy for jumping. To derive the relation between the elastic energy stored in the spring and the jumping height, the guard robot is modeled as a body-spring-foot system, as shown in figure 1. To jump from the ground, the robot accumulates the elastic energy by compressing the spring at first (i.e., (a) → (b)). At the moment which the robot is about to jump, the robot releases the spring immediately, thus converting the elastic energy into the kinetic energy. Then the body moves vertically up and passes through the initial position at a velocity of v_1 (i.e., (b) → (c)). Since the inertial force acts on the body, the foot departs from the ground with a velocity of v_2 (i.e., (c) → (d)). The jumping height reaches a maximum value when $v_2 = 0$. The jumping height h can be obtained by applying both the energy conservation law and the momentum conservation law as follows:

$$h = \frac{1}{g}\frac{m_b}{(m_b + m_f)^2}\eta_{eff} E_s \qquad (1)$$

where g is the gravitational acceleration, m_b and m_f are the mass of the body and the foot, E_s is the elastic energy of the spring, respectively. η_{eff} is the mechanical efficient that is dominantly affected by the friction force occurring in the system.

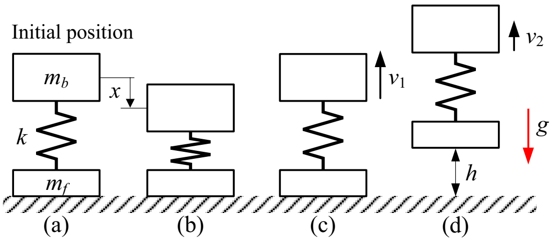


Figure 1 Jumping model; (a) initial state, (b) compressing, (c) releasing and (d) jumping.

Equation (1) indicates two main factors for the jumping mechanism. One is the force-deformation characteristic of the spring, which is associated with E_s. Since the output torque of the jumping motor as well as the space available for the mechanism are limited, E_s has to be maximized under these limitations. Another factor is the power transmission system connected to the spring, which is associated with η_{eff}. The path of the power transmission system has to be minimized to increase η_{eff} when the robot jumps. To do this, the clutch system is needed to engage or disengage the power transmission according to the situation. To satisfy the design requirements stated above, the conical spring and the clutch system based on a planetary gear train are used, as shown in figure 2. The conical spring that is the key element in the jumping module is discussed first, and then the clutch system is dealt with later.

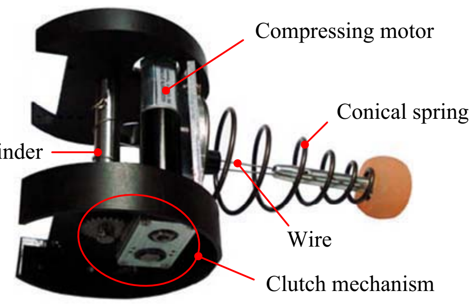


Figure 2 Jumping module composed of clutch mechanism and conical spring.

2.1 Conical Spring

A conical spring, which is the representative nonlinear spring, has different diameters at both ends of the spring, as shown in figure 3(a). Therefore, all the spring wires can be nested as the spring compresses, as shown in figure 3(b). It means that the conical spring is good for the use in the space limited in the axial direction [5]. With the conical spring, the length of compression can be maximized and buckling occurring frequently for the general coil spring can be avoided.

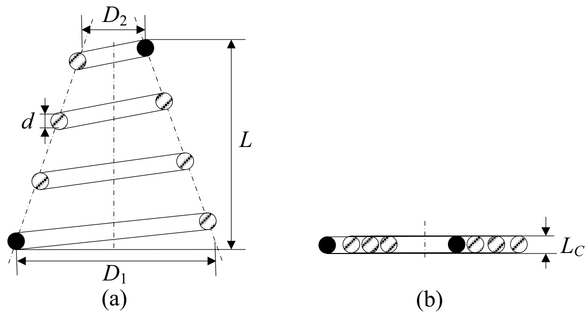


Figure 3 Conical spring: (a) initial state, and (b) fully compressed.

The characteristic of a conical spring can be divided into the linear, nonlinear and solid regions, as shown in Fig. 4. The integrated area and the tangent line of the graph mean that the elastic energy E_s and the spring rate k, respectively. As the spring is compressed, the spring rate increases whereas the mean diameter D and the number of active coils N decrease. The spring rate k can be given by

$$k = \frac{d^4 G}{8D^3 N} \tag{2}$$

where d is the diameter of the spring wire and G is the shear modulus [6].

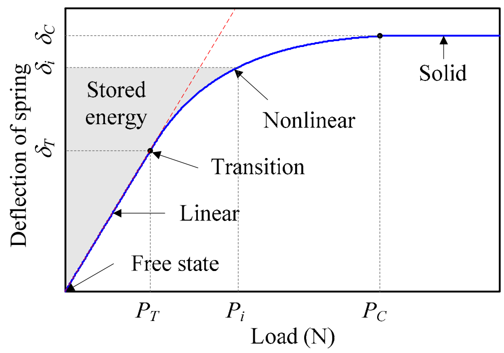
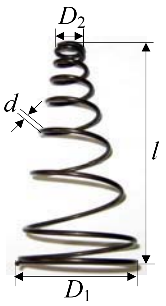


Figure 4 Graph of load-deformation relation.

The size of a spring for the jumping robot is determined by the mass, size, and jumping height of the robot. The design specifications for the jumping robot proposed in this research are 30x30x30cm^3 in size, 3kg in mass, more than 10cm in the jumping height. From these requirements, the desired specifications for the conical spring can be obtained, as shown in Table 1. Figure 5 shows the fabricated conical spring and its specifications. A piano wire whose shear modulus is 78x10^{3}N/mm^2 was used for the spring wire.

Table 1. Desired specifications of spring for jumping robot.

Desired parameters	Desired specification
Largest diameter	< 70mm
Maximum load	> 300N
Solid height	< 35mm
Free length	< 150mm
Elastic energy	> 5J



Largest diameter of spring, D_1	70mm
Smallest diameter of spring, D_2	20mm
Diameter of wire, d	3mm
Transitional load, P_T	50N
Maximum load, P_C	300N
Number of coils, N	8
Solid height, lc	20mm
Free length, l	150mm

Figure 5 Manufactured conical spring and its specifications.

To verify the spring characteristics, the deflection was measured in accordance with the applied load. Figure 6(a) shows the relationship between the applied load and the deflection. By differentiating the applied load-deflection graph, the spring rate-deflection curve can be obtained, as shown in figure 6(b). The spring rate increases nonlinearly as the deflection of the spring increases. These curves can be used to estimate the jumping height.

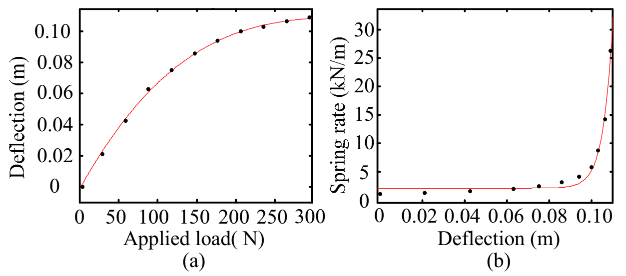


Figure 6 Experimental results; (a) load-deflection curve, and (b) deflection-spring rate curve.

2.2 Clutch Mechanism

The jumping mechanism is composed of a planetary gear train (A) and a one-way clutch (B), as shown in figure 7. A general planetary gear train, which has 2 DOF characteristics, consists of a sun gear, a planet gear and an internal ring gear. If the ring gear is fixed to the ground and the sun gear is connected to the motor input, then the carrier functions as an output of the planetary gear system. In the jumping mechanism, however, the ring gear was removed and the one-way clutch composed of a ratchet, a pawl and a leaf spring was adopted to complement this insufficient DOF as well as to provide the function of the clutch

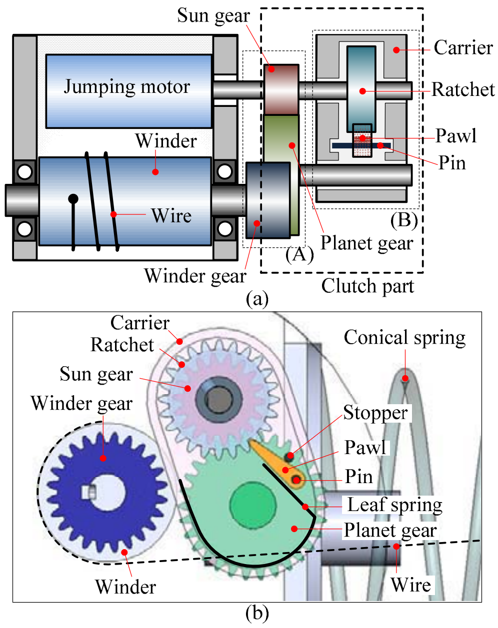


Figure 7 Jumping module; (a) top view, and (b) side view.

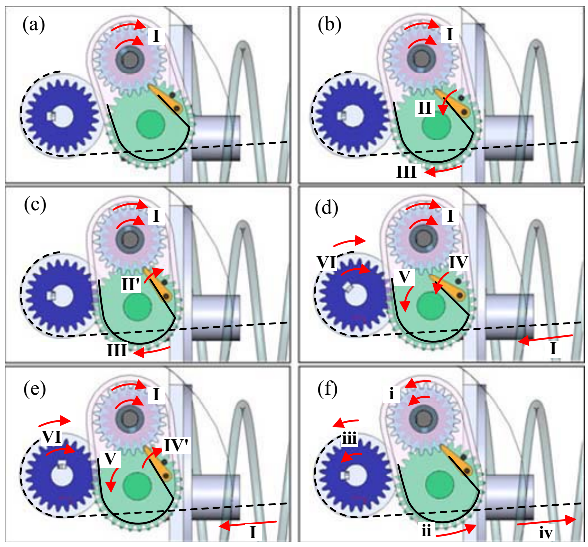


Figure 8 Sequence for jumping.

To give a better understanding, the jumping sequence is illustrated in figure 8. As the jumping motor rotates CW, both the sun gear and the ratchet rotate CW (i.e., I). The ratchet pushes the pawl to rotate CCW (i.e., II), but the leaf spring, which is mounted on the carrier together with the pawl, resists the rotation of the pawl (i.e., II') at the same time. To prevent the relative motion from occurring between the sun gear and the carrier, small spring force is required to overcome the gravitational force acting on the clutch part. Then the carrier rotates the same direction as the sun gear whereas the planet gear approaches to the winder gear (i.e., III). In this case, the motor power is transmitted to the carrier through the ratchet, the pawl and the leaf spring. Consequently, the planet gear is engaged with the winder gear. After this engagement, the carrier can no longer rotate even though the jumping motor still rotates. When the ratchet pushes the pawl to rotate CCW (i.e., IV), the ratchet can rotate relative to the carrier since the spring force is smaller than the force transmitted from the motor. Then the planet gear rotates CCW (i.e., V) and the winder gear rotates CW (i.e., VI). Finally, the spring is compressed as the length of the wire decreases.

In contrast to the compressing motion, the releasing motion represented in figure 8(f) is simple. When both the sun gear and the ratchet rotate CCW (i.e., i), the ratchet pushes the pawl to rotate CW. However, the stopper blocks the rotation of the pawl, the carrier rotates CCW (i.e., ii) since the motor power is transmitted to the carrier directly. As a result, both of the winder gear and the planet gear are disengaged (i.e., iii) and the spring is released at once (i.e., iv). With this jumping mechanism explained above, the jumping action is not related to the amount of spring, which is important for control of the jumping height.

3. Guard Robots

The small-sized, lightweight and low-cost jumping robot equipped with the jumping mechanism stated before was fabricated, as shown in figure 9. The system can be classified into the guard robot part and the remote control part. The guard robot is composed of a body, a driving module and a jumping module. The body and wheels are made of polycarbonate and polyurethane, respectively, which can absorb and distribute a large external force applied to the robot. The size of the robot is 15cm (diameter) x30cm (length) and the mass is about 2.7kg including the batteries.

The robot uses three 7W DC motors including speed reducers and encoders. The gear ratio of the driving motor is 15:1, while that of the jumping mechanism is 690:1. The DSP2812 with small motor driver ICs were used to control motors and the command signals transmitted from the remote controller by using the Bluetooth communication. To provide the environment information to the operator, the wireless LAN camera (Axis 207W) including the communication board is installed at the robot. The operator can receive the visual information with the computer connected to the wireless LAN AP.

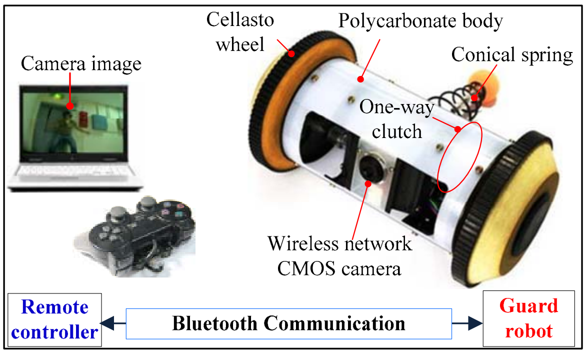


Figure 9 System of guard robot.

Various experiments were conducted to evaluate the performance of the robot's mobility. The robot can run at a maximum speed 2m/s on the normal terrain and it takes about 7 sec for compressing the spring. As shown in figure 10(a), the robot can jump up to 40cm vertically from the ground. When the robot encounters an obstacle as shown in figure 10(b), the robot can jump with the jumping angle of 60° so that the robot can overcome it.

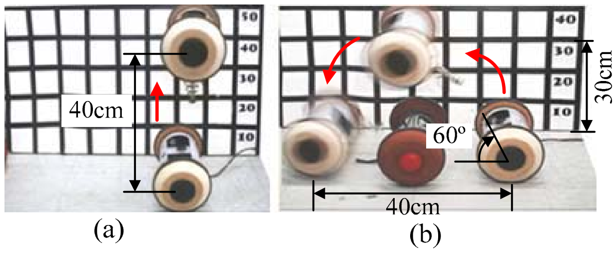


Figure 10 Jumping experiments; (a) vertical jumping and (b) jumping with jumping angle of 60°.

Figure 11 shows the sequence of climbing the stairs by jumping. The size of the stairs used in this experiment was 15cm(H)x30cm(D)x50cm(W) for each step. The robot was controlled by remote control and it took about 35 sec climb three steps.

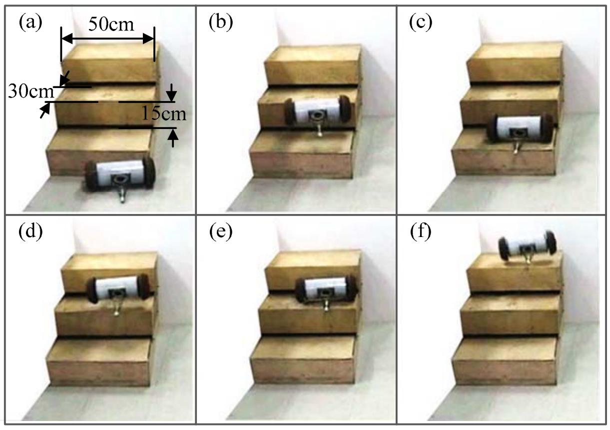


Figure 11 Experiments on stair climbing.

4. Applications: Patrolling

Not only a robot can move fast on the fine terrain with two wheels but also it can travel on the rough terrain with a jumping module, so the proposed guard robot is applicable to a variety of indoor/outdoor applications. Figure 12 shows the demonstration of patrolling by using a guard robot and that is one of the most popular applications for the social security robot. The operator such as a security guard manipulates the robot with the visual information provided by the camera. When the robot encounters the obstacle during the operation, it can jump over the obstacle and reach to the desired place. As shown in figure 12(b), two fire extinguishers(15cm diameter and 45cm height) were used to block an entrance where the robot has to go through. Once a stranger is detected, the operator identifies him with the camera information first, and then notifies him that place is being protected.

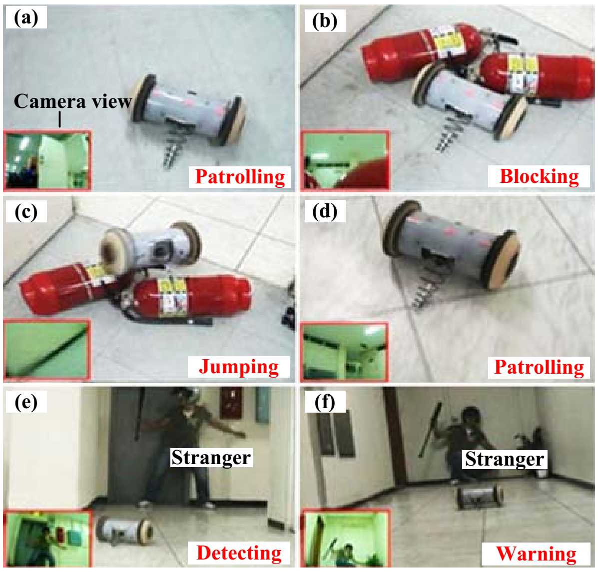


Figure 12 Application of guard robot; patrolling.

5. Conclusions

In this research, the jumping mechanism was proposed to improve the mobility of a small robot. The portable robot capable of jumping was constructed and the performance of driving and jumping were investigated through a series of experiments. From this research, the following conclusions are drawn:

(1) The structure of the jumping mechanism based on a conical spring is compact enough to fit into the small jumping robot.

(2) The proposed clutch system using a planetary gear train and a one-way clutch enables the robot to compress or release a spring with a single motor.

Besides patrolling, the guard robot can be thrown into the scene of a fire or a crime, and it can provide the image of the scene using the built-in camera. Furthermore, there are some military applications such as reconnaissance and watching and so on.

Acknowledgments

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