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# Design on hopping locomotion mechanism

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**Abstract:** A new type of locomotion mechanism is introduced in this paper. With vibrating motors used in controlling the movement of the hopping locomotion mechanism, the simple hopping locomotion mechanism had two motors, when the current went through the vertical motor, the vertical motor would vibrate to cause the mechanism to go forward, and when the current went through the horizontal motor, the mechanism will go around itself. A spring was added to the mechanism to change the natural frequency of the mechanism, when the frequency of the motor was equal to the natural frequency of the mechanism, the mechanism would hop resonantly. With the resonant hopping, the load of the mechanism was greatly enlarged, and some sensors could be added to the mechanism. Optical sensors were used to detect the infrared source, the current that went through the sensors related to the distance between the infrared light. Three optical sensors was put on the left, right and the front the mechanism, when the mechanism detect the special infrared source, it would turn itself to the light, and go forward to the light. The experiments of the mechanism shown that the mechanism could work well on different surfaces freely, and the resonant hopping locomotion mechanism with infrared sensors could move to the special light by automatic regulation. Experimental results and theoretical studies demonstrate that the innovative design for hopping locomotion mechanism is superior.

**Key words:** robot hopping locomotion mechanism; friction; infrared sensor; resonance

## 1 Introduction

Large machines have been widely used in industry recently. They will cause complex operations and require a great deal of energy. The high-energy problem has come to the attention of more and more people, so pint-sized robots have been researched to save energy<sup>[1]</sup>. Now pint-sized robots often use electromagnetism as their driver<sup>[2]</sup>, they also need high voltage and special flat surfaces of iron. In this article a new pint-sized hopping locomotion mechanism which saves energy and adapts well to various surfaces is presented.

## 2 Principle

### 2.1 Motor

The image of the motor is shown in Fig. 1. The stator of the motor, the magnet, is fixed to the motor, and the rotor is made from a prejudicial wheel. When the power is on, the prejudicial wheel will turn around the axis, and the motor will circumrotate in the opposite direction. When the motor is fixed to the mechanism and the power is on, the mechanism will be vibration. Then, the vibration and friction introduced from surface will lead the mechanism to move and turn around.

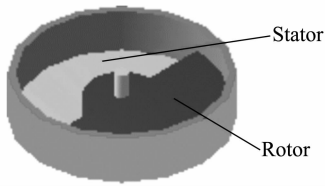


Fig. 1 Image of motor

## 2.2 Kinematics of simple hopping locomotion mechanism

There are two motors in the simple hopping locomotion mechanism. When the current goes through the vertical motor, the vertical motor will vibrate to cause the mechanism to go forward. When the current goes through the horizontal motor, the mechanism will go around itself.

### 2.2.1 Movement of going forward

When the vertical motor vibrates, the centripetal force of rotor will also affect all the mechanism. When the motivity of the motor (it nearly equals the centripetal force of the rotor of the motor) is bigger than the weight of the mechanism, the mechanism will go up. In the vertical direction, the movement can be calculated by equation 1.

$$-M_{\text{robot},g} + F_A \cos(\omega t) = M_{\text{robot}} \ddot{z}, \quad (1)$$

Where  $-M_{\text{robot},g}$  means the weight of the mechanism,  $F_A$  means the motivity of the motor,

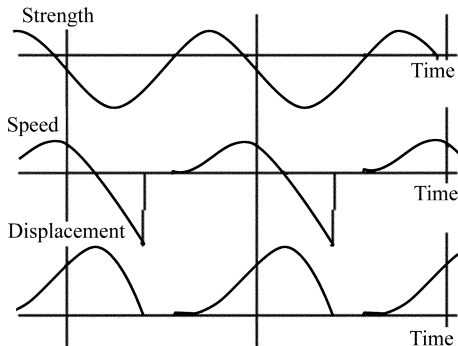


Fig. 2 Image of the strength, speed and displacement of the mechanism in the vertical direction

and  $\ddot{z}$  means the vertical displacement of the mechanism.

After the mechanism falls down to the ground, the vertical speed and displacement of the mechanism will be zero until the motivity of the motor is bigger than the weight of the mechanism again.

The vertical strength, speed and displacement of the mechanism can be shown in Fig. 2.

In the horizontal direction, the friction and motivity of the motor affect together. The friction can be calculated by equation 2.

$$F_f = f(M_{\text{robot},g} - F_A \cos(\omega t)), \quad (2)$$

Only when the mechanism falls down to the ground, the friction works, and at the other time, the friction is equal to zero. The friction is shown in Fig. 3.

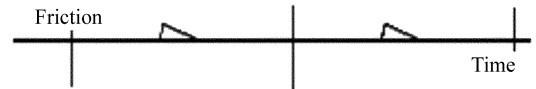


Fig. 3 Image of friction of the simple hopping locomotion mechanism

The horizontal movement of the mechanism can be calculated by the equation 3.

$$F_A \sin(\omega t) \pm F_f = M_{\text{robot}} \ddot{x}, \quad (3)$$

The direction of the friction is the reversed direction of the speed, so, in equation 3,  $\pm$  is used to indicate the direction of friction.

The movement of the mechanism can be seen in Fig. 4 according to equation 3.

In the image of strength (Fig. 4), the broken circle means the effect by the friction. The speed of the mechanism is changed by the friction, the mechanism goes forward in a cycle, and it can go in the forward direction cycle by cycle.

The image of the movement of the mechanism can be seen in Fig 5 according to its vertical

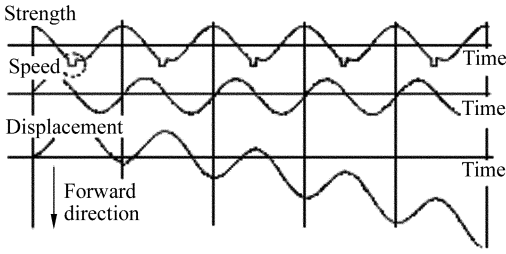


Fig. 4 Image of the strength, speed and displacement of the mechanism in the horizontal direction

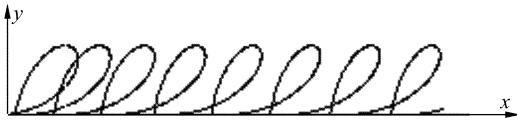


Fig. 5 Image of the movement of the simple hopping locomotion mechanism.

and horizontal movements.

2.2.2 Movement of turning around itself

When the current goes though the horizontal motor, the rotor will turn around itself. So the other parts of the mechanism will turn around in the reverse direction according the balance of moment. The movement module can be shown in Fig. 6.

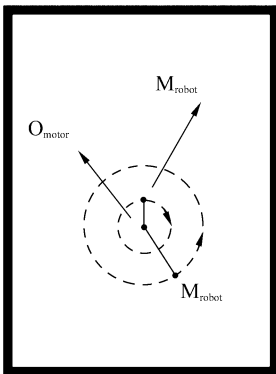


Fig. 6 Movement module of the simple hopping locomotion mechanism.

$\omega_{robot}$  can be calculated by equation 4. Thereinto,  $D$  means the distance between the center of gravity of the mechanism and the center of the motor.

$$M_{robot} D \omega_{robot}^2 = M_{rotor} R_{rotor} \omega_{rotor}^2 \tag{4}$$

2.3 Kinematics of the resonant hopping locomotion mechanism

The load of the simple hopping locomotion mechanism is limited by the tension of the power. If the mechanism becomes heavier, the tension must be higher to keep its speed. Since the tension of the motor can not be bigger than 2.0 voltages, the load is also limited by the power. The resonant hopping locomotion mechanism is researched to enlarge the load.

The module of the resonant hopping locomotion mechanism is shown in Fig. 7. Since the new mechanism's motor and movement of turning around itself are the same as the simple one, only the movement of going forward is introduced in the next section.



Fig. 7 Module of the resonant hopping locomotion mechanism

A spring is used to connect the motor and the body of the mechanism when the current goes through the motor, with the motivity of the motor, the spring will waggle. Suppose that of the body of the mechanism is much smaller than that of the spring, that of the body can be ignored and the speed can be calculated by equation 5.

$$\left(m + \frac{1}{3} m_k\right) l \ddot{\theta} + k l \theta = F_A \sin(\omega t) \tag{5}$$

The vertical movement can be calculated by equation 6.

$$-M_g - Kl\theta \cos \alpha = M\ddot{y}, \quad (6)$$

And the horizontal movement can be calculated by equation 7.

$$Kl\theta \sin \alpha \pm F_f = m_b \ddot{x}, \quad (7)$$

Thereinto,  $F_f$  means the friction. When the vertical displacement  $y > 0$ , the friction  $F_f = 0$ , and when  $y = 0$ ,  $F_f = (M_g + Kl\theta \cos \alpha) f$ .

From equation 5, 6 and 7, the horizontal movement can be calculated by equation 8 when the vertical displacement  $y > 0$ , or by equation 9 when  $y = 0$ .

$$\ddot{x} = -\frac{KF_A \sin \alpha}{m_b \left\{ \left( m + \frac{1}{3} m_k \right) \omega^2 - K \right\}} \sin(\omega t), \quad (8)$$

$$\ddot{x} = -\frac{KF_A \sin \alpha \pm KfF_A \cos \alpha}{m_b \left\{ \left( m + \frac{1}{3} m_k \right) \omega^2 - K \right\}} \sin(\omega t) \pm \frac{M_g f}{m_b}, \quad (9)$$

Thereinto,  $K$  means the elastic ratio of the spring, which is decided by the shape and the material of the spring, and it can be changed easily. If  $\left( m + \frac{1}{3} m_k \right) \omega^2 - K \Rightarrow 0$ , the movement will become very strong, even if the current is not so big. Then the load of this mode can be much heavier than the simple one.

## 2.4 Kinematics of going to the infrared special light

Since the load of the resonant hopping locomotion mechanism can be enlarged, some sensors like optical sensors can be added to the mechanism which can make the mechanism approach to the infrared light.

The module of the mechanism with optical sensors is shown in Fig. 8. The circuit is shown in Fig. 9. M means the motor and S means the sensor. If the infrared comes from ahead, the current will go through the vertical sensors and

the vertical motor. The vertical motor will hence vibrate and the mechanism will go ahead. If the infrared comes from the right side, the current will go through the right sensor and the right motor and the mechanism will turn to the right side according to the kinematics introduced in chapter 2.2.2.



Fig. 8 Module of the resonant hopping locomotion mechanism with optical sensors.

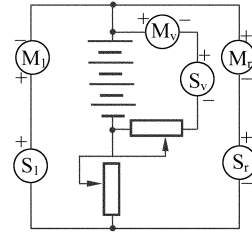


Fig. 9 Circuit of optical sensors.

## 3 Experiments

### 3.1 Conditions of the experiments

The motor FM26A is made by the company of Tokyo, whose diameter is 13.6 mm, the mass of rotor is 7.2 g, the standard speed is 3 200 r/min and the low voltage of the motor from 1.0 V to 1.5 V. Button batteries such as LR44 and SR44 can be used as the power of the motor.

The experiments are done in the surface of rigid aluminum, plastic, wood and even the keyboard.

### 3.2 Movement of the simple hopping locomotion mechanism

The simple hopping locomotion mechanism is shown in Fig. 10. When the current goes

through the horizontal motor, the mechanism will turn around itself and the speed will increase with the voltage. When the voltage is 1.5 V, the speed will be  $4\pi/s$ . When the current goes through the vertical motor, the speed on the different surfaces is shown in Tab. 1 with 1.5 V voltage.

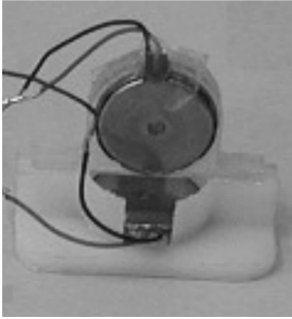


Fig. 10 Simple hopping locomotion mechanism

Tab. 1 Speed on the different surfaces

Surface	Aluminum	Plastic	Wood	Key-board
Speed mm/s	30.0	22.2	25.0	5.0

### 3.3 Movement of the resonant hopping locomotion mechanism

The resonant hopping locomotion mechanism is shown in Fig. 11. The speed of the mechanism depends on the elastic ratio of the spring. Changing the length, the width, the height or the material of the spring will cause the change of the elastic ratio. When the load of the mechanism is changed, the elastic ratio should also be changed to make the mechanism vibrate resonantly. The highest speed of the mechanism of this type can be 74.0 mm/s with the least load.

### 3.4 Movement of the resonant simple hopping locomotion mechanism with optical sensors

The resonant hopping locomotion mechanism with infrared sensors is shown in Fig. 12. The optical sensor which can receive the infrared ray is PS3322. When the infrared ray becomes more and more, the resistance of the optical sensor will become smaller and smaller. The Na-



Fig. 11 Resonant hopping locomotion mechanism

tional silica lamp made in Japan is used as the light source. It has been tested that the resonant hopping locomotion mechanism with infrared sensors can move to the lamp when the distance between the lamp and the mechanism is smaller than 1 m.



Fig. 12 Resonant hopping locomotion mechanism with optical sensors

## 4 Result and conclusion

The hopping locomotion mechanism driven by small vibrating motors can move on a series of surfaces by hopping. The voltage of the motor is only 1.2~1.5 V, so the button battery can be used as the power to save energy.

The natural frequency can be changed by the elastic ratio of the spring, so the load of the mechanism has been enlarged greatly by resonant vibration.

Three optical sensors have been added to the mechanism, so it can move to a special lamp and can be used in some automatic control systems.

It has been tested that the hopping locomotion mechanism can move freely in a 2D platform, and it can be used in some automatic control systems with special sensors.

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**Brief professional biography of the author:**

**LU Yong-kui:** Male, (1975—), got bachelor degree in 2000 from the University of Science and Technology of China, and got doctor degree in 2005 from the same university. His research interests are robotics and especially fuzzy control.