소형 점핑 이동로봇의 개발

Development of a Small Jumping Mobile Robot

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1. Introduction

Compared to other locomotion gaits. the jumping gait has advantages in terms of the travel speed and the energy efficiency. In addition, mobile robots employing the jumping locomotion can be less dependable on the type of terrain. Therefore jumping creatures have inspired robotics scientists and engineers to investigate and develop jumping mechanisms and control methods. Some examples to mimic the musculoskeletal systems of biological creatures can be found in the multi-DOF (degree of freedom) the Mowgli robot [1] and the rabbit robot [2].

The jumping gait entails an extremely large force in a short time. Therefore, the pneumatic actuator is often chosen for the jumping mechanism. The pneumatic actuator has a larger power-to-weight ratio than the electromagnetic motor [3]. In addition, the pneumatic actuator produces the linear motion, which is closer to the behavior of muscles than the rotation of the electromagnetic motor. However, the pneumatic actuator tends to make robots heavier and larger due to the complexity of pneumatic systems and its power supply source.

SMA (Shape Memory Alloy) has an enormous potential to be used for jumping robots because SMA is one of the actuators that have the largest power-to-weight ratio [3]. Motivated by the incorporation of the smart material in a clever robot design, this paper presents the development of a small jumping robot. The design of robot structure is inspired by vertebrates' musculoskeletal system and the jumping mechanism is actuated by SMA wires. The use of SMA for jumping robot is expected to reduce the weight and the complexity of the robot while still maintaining the functions of muscles in jumping.

2. Robot design

Studies on human's musculoskeletal system show that the whole movement of lower limbs is realized by nine muscle groups and tendon system combined with the skeleton system as shown in Fig. 1a [4,5]. In order to investigate the human's jumping action, the whole body is divided into four segments. The trunk includes parts in the upper side of the hip. The upper leg or the thigh is the segment between the hip and the knee. The lower leg or the shank is represented by the segment from the knee to the ankle. The plantar part or the foot is the last segment attached at the ankle. The lateral motion in jumping is neglected, and so three joints attached at the hip, the knee, and the ankle are considered as revolute ones.

According to the effects of the muscle on the movement of leg joints, the nine muscle groups in the lower limbs are classified into two muscle types. The first type is called a mono-articular muscle which acts on only one joint. The iliopsoas (ILI), gluteus maximus (GMAX), vastus group (VAS), biceps femoris (BF), tibialis anterior (TA), and soleus (SOL) belong to this type. The bi-articular muscle, on the other side, are connected to control two joints of the leg. In Fig. 1, the rectus femoris (RF), hamstrings (HAMS), and gastrocnemius (GAS) are three bi-articular muscle groups.

Our design aims to simplify the biological structure while keeping the functions of both muscle types as much as possible. In this work, we present a simplified leg model for jumping in which the same number of segments is kept as in the real leg. However the number of muscles is reduced to three and each muscle is to be replaced by an SMA wire. Fig. 1b displays the design concept of the robot leg. Since the number of artificial muscles is reduced significantly, several passive springs are added with the SMA wires at each joint to form the flexor – extensor pairs.

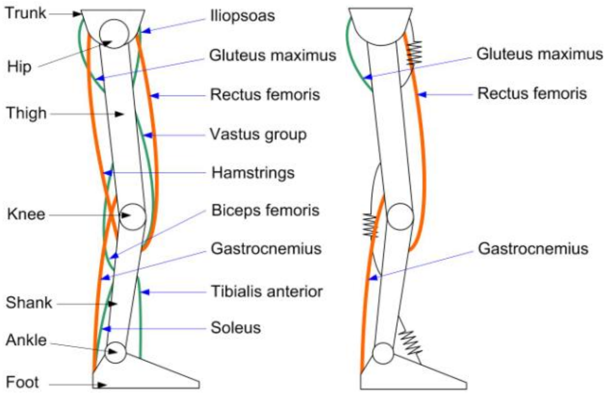

Fig. 1 (a) The musculoskeletal system of the human's leg. (b) Simplified leg in the robot.

In order to increase the stability of the robot in landing is increasing the number of legs. It is also found from the nature that successful jumping vertebrates like a frog and a rabbit use four legs for the jumping. This explains the reason why the jumping robot presented in this paper possesses four legs. The side view of our jumping robot design is illustrated in Fig. 2.

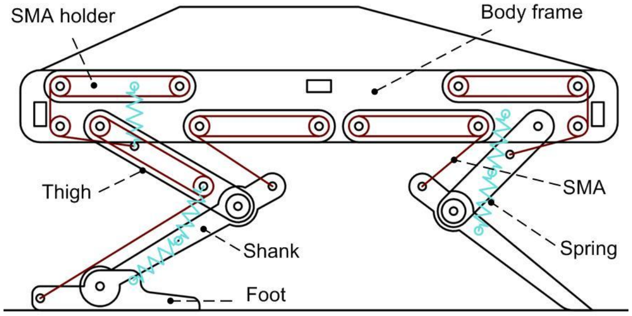

Fig. 2 Model of the four-legged jumping robot.

3. Robot prototype and experiments

Based on the robot design in Sec. II, a prototype of the jumping robot has been fabricated, as shown in Fig. 3. Acrylic is mostly used to make the leg segments as well as the body frame. Each part was designed with AutoCAD and fabricated using a CNC machine. Lightweight pulleys are utilized to form the SMA holders. Each MMF150 SMA wire is about 200 mm long and is wound around the pulleys. Ten springs with a low stiffness are inserted to form the flexor-extensor pairs with the SMA wires. The length, width, and height of the prototype are 150 mm, 65 mm, 65 mm, respectively. The weight of the legs takes about 20 % of the total weight, which is 80 gram.

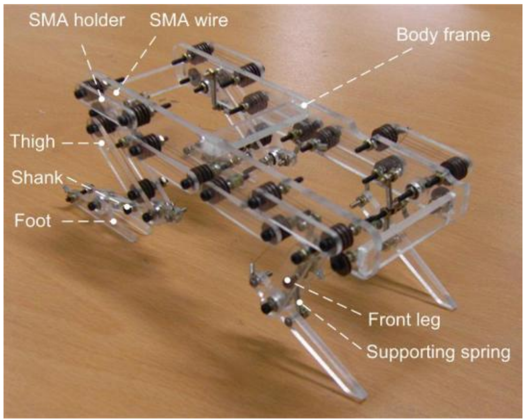

Fig. 3 The jumping robot prototype.

In our experiments with the prototype, the muscle activation scheme obtained through the simulation is applied (see Table 1). Since any transverse motion is not desired in the experiments, each pair of symmetrical SMA wires is controlled by one signal. Therefore five control lines are needed to control ten SMA wires. The control work is done off-board by an external control circuit.

Table 1 Activation sequence for the SMA wires

	SMA1	SMA2	SMA3	SMA4	SMA5
Time (ms)	-150	-150	-100	-130	-80
Speed (mm/s)	20	20	70	20	90

All the jumping experiments were conducted on the plywood plate and the off-board control circuit was used to control the SMA wires. The SMA wires are controlled by combined pulse. The width of pulse in Fig. 4b defines the contraction period of the SMA wire. We can also control the contraction speed by using another signal named pulse width modulation signal (PWM). By this setting, the robot can jump forward by 25 mm in each jump. This result is comparable to the simulation result. The total period of time from the start of jumping to the landing is about 3 sec in which the elongating time of SMA wire takes more than 90%. Three snapshots of the jumping experiment are displayed in Fig. 4. The frame #1 shows the robot before it starts jumping. The flying phase is shown in frame #2 and the landing moment is captured in frame #3.

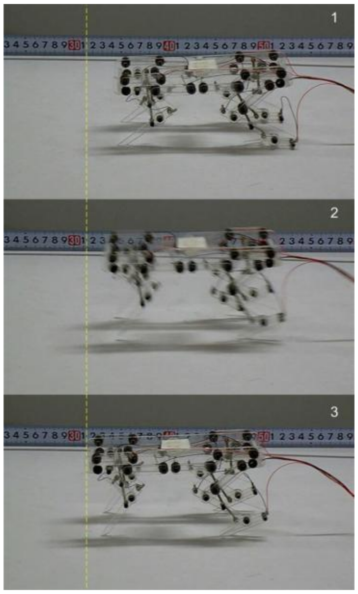

Fig. 4 Snapshots of the robot prototype in jumping.

4. Conclusion

We presented the development of four-legged jumping robot that is actuated by SMA wires only. The design of robot is inspired from vertebrates' musculoskeletal system. The functions of mono-articular and bi-articular muscle types are studied carefully and applied in the simplified fashion. The four-leg configuration robot is chosen to increase the stability of the system during the landing after the flying phase. The parameters obtained from the simulation are applied to a robot prototype in experiments. The forward distance obtained from the jumping experiment is about 25 mm. The experiments with 50 gram load on the robot with the same activation scheme yielded the same result in terms of the forward distance.

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