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High-performance transmission mechanism for robotic applications

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ABSTRACT

High-performance transmission mechanisms are essential for robotic applications, since they affect overall weight, motion speed and actuation force. An innovative high-performance transmission mechanism with a single motor has been designed, analyzed and developed. The proposed mechanism can achieve a high-speed motion in Mode I and generate a large actuation force in Mode II. It is used to actuate an anthropomorphic finger, allowing it to produce fast bending motions and large contact forces, but it could be adopted in all those applications where high speed and large force are required. Detailed performance analysis is presented as well as experimental measurements showing successful fulfilment of requirements. The maximum velocity of the transmission mechanism is about 96.1mm/s, and the measured actuation force is about 377N.

1. Introduction

The development of high-performance (e.g. high-speed motion and large output force) transmission mechanisms is one of the unresolved scientific problems for light-weight, compact, and efficient robotic applications. One of the most representative applications is the actuation of anthropomorphic hands which require fast free bending motions and large contact forces.

For a given conventional electromagnetic motor, its power P is constant. The electromagnetic motor can output a large actuation torque if the actuation speed is small. Conversely, a high-speed rotation can be obtained only when the actuation torque is small. That is to say, high-speed motion and large actuation force cannot be obtained simultaneously for given electromagnetic motors. To improve performance of actuation systems, various high-performance actuators have been used for robotic applications. Typical examples of these actuators from literature are, for instance, the shape memory alloy actuators [1, 2], electroactive polymer actuators [3, 4], pneumatic actuators [5, 6], and ultrasonic motors [7, 8]. These new actuators may meet some of the expected characteristics (high speed, large output force and light weight), but not all of them.

Efficient high-performance transmission mechanisms have also received a lot of attention in parallel to achieve desired high-performance actuation systems. K. Matsushita et al. have designed a continuously variable transmission to achieve efficient motions by load-sensitively adjusting the reduction ratio of the actuator [9]. Several high-performance transmission

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mechanisms have also been proposed for robotic hands [10–12] and parallel jaw grippers [13]. These transmission mechanisms are simple and efficient. However, some of them are still too heavy and large for small and compact robots, and the actuation forces applied by the mechanisms in [10–13] are uncontrollable and depend on the joint values of the fingers or grippers.

Besides the aforementioned methods, T. Takaki et al. have designed a non-back-drivable flexion actuation system and a force-magnification mechanism to meet force and speed requirements simultaneously [14]. Y. J. Shin et al. have introduced a dual-mode twisting mechanism, which can move fast in the speed mode and can exert large output force in the force mode [15, 16]. These two mechanisms can achieve high-performance motions by means of a dual-mode drive method. However, the former needs an additional motor to drive the force-magnification mechanism and the latter takes long time in the relaxing process.

The transmission mechanism proposed in this paper is inspired by the dual-mode drive method presented in [14–16]. The main contribution of our work is the development of an innovative, (1) light-weight, (2) compact, (3) high-performance (high speed and large actuation force) transmission mechanism with (4) a single motor. This paper is organized as follows. In Section 2, the principle of the proposed high-performance transmission mechanism is introduced. Section 3 analyses the performance of the mechanism. Section 4 describes the implementation of the mechanism and the application in robotic fingers. Experimental measurements are presented in Section 5.

2. Methods

The proposed high-performance transmission mechanism is shown in Fig. 1. The mechanism consists of a motor (1), a support link (2) fixed to the motor shaft, two levers (3) that are under the action of a compression spring (4), a pin (5), a twisting shaft (6) with two grooves, a fixed twisting coupling (7), and two strings (8). Referring to Fig. 1, the twisting shaft (6) and the twisting coupling (7) are coaxial with the motor shaft. The twisting shaft (6) can rotate freely relative to the twisting coupling (7). One end of each string, which comes through the holes of the twisting shaft (6) and the twisting coupling (7), is fixed to the corresponding lever (3), and the other end is free or mounted on robotic applications. It's noted that the two levers (3) can rotate around the pin (5) when the tension force of the strings exceeds the action force of the compression spring (4).

The principle of the proposed transmission mechanism is illustrated in Fig. 2. In the initial state, the levers are embedded in the grooves of the twisting shaft, and the twisting shaft can rotate synchronously with the motor. The strings start to twist on the twisting shaft once the motor drives the support link (together with the levers and the twisting shaft). During this motion mode (Mode I), the strings contract quickly which implies that the transmission mechanism produces a high-speed motion. When the tension force of the strings reaches the pre-set value, the levers begin to rotate around the pin. As a result, the levers are free from restrains of the grooves. Thus, the motor will drive the support link and the levers while the twisting shaft does not rotate. During this motion mode (Mode II), the strings between the levers and the twisting shaft are twisted and produce a large actuation force.

The mechanism can control the switching from one mode to the other automatically. Assume that the mechanism works in Mode I in the initial state. When the tension force of the strings reaches the pre-set value, the levers would be free from restrains of the grooves. As a result, the motion mode would switch from Mode I to Mode II. Conversely, if the mechanism works in Mode II firstly, the twisted strings between the levers and the twisting shaft would be unwound when the motor rotates reversely. Once the tension force becomes smaller than the pre-set value, the motion mode would switch from Mode II to Mode I. The contraction velocity of the strings and actuation force will be analyzed in the next section.

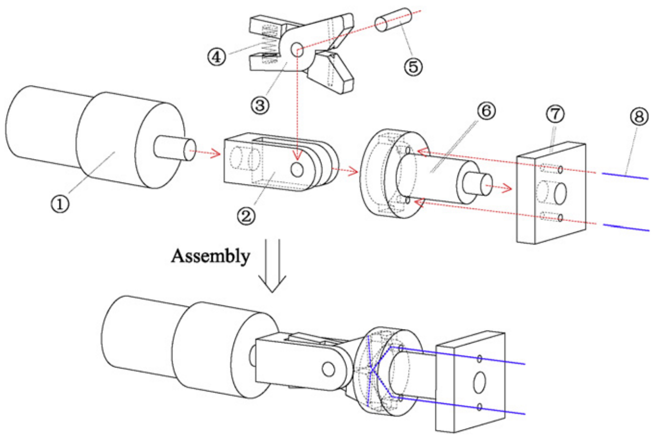

Fig. 1. Mechanical structure of the transmission mechanism.