Implementation of a Variable Stiffness Joint Based on the Twisted String Actuators

G. Palli, L. Pan, M. Hosseini, L. Moriello, and C. Melchiorri
DEI - Università di Bologna, Viale Risorgimento 2, Bologna, Italy

Abstract—In this paper, the modeling and the control of a variable stiffness joint actuated by a couple of twisted string actuators in antagonistic configuration is reported. The twisted string actuation system is particularly suitable for very compact and light-weight robotic devices, like artificial hands and arms, and renders a very low apparent inertia at the load side, allowing the implementation of powerful tendon-based driving systems, using as actuators small-size DC motors characterized by high speed, low torque and very limited inertia. The basic properties of the twisted string actuation system are presented, and the way how they are exploited for the implementation of a variable stiffness joint is discussed. A control algorithm based on the feedback linearization of the device is used for tracking the desired position and stiffness profile. Preliminary experimental results are reported to validate the proposed control approach.

Index Terms—Variable Stiffness, Twisted String Actuation, Tendon Transmission System.

I. INTRODUCTION

The Twisted String Actuation concept [1] allows the implementation of a very compact and low cost linear actuation system. As a matter of fact, with an appropriate choice of the rotative electric motors and of some design parameters of the strings (in particular the radius and length), it is possible to satisfy all of the tight requirements for the implementation of miniaturized and highly-integrated mechatronic devices. Indeed, this actuation mechanism has been already successfully used for the implementation of different robotic devices like robotic hands [2], [3] and exoskeletons [4]. The characteristics and the mathematical model of the twisted string actuation systems and, in particular, the analysis of its force/position characteristic and of the resultant transmission stiffness has been investigated in [1]. The model of the twisted string actuation system has also been recently improved taking into account the characteristics of different type of strings in [5].

The basic idea of the actuation system is quite simple and is illustrated schematically in Fig. 1: one or more strings are connected in parallel on one end to a rotative electrical motor and on the other end to the load to be actuated. The rotation imposed to the strings by the electrical motor reduces their length, generating a linear motion at the load side. This actuation concept, because of its high (though nonlinear) reduction ratio, permits the use of very small and lightweight electric motors and therefore is very interesting in applications where size and weight are of crucial importance.

In this paper, the use of the twisted string actuation principle for the implementation of variable stiffness mechanisms is investigated. With reference to Fig. 2 where a schematic representation of the experimental setup is reported, the system is composed by a couple of twisted string actuators in antagonistic configuration connected to a rotative joint. The intrinsic non-linear and configuration-dependent stiffness characteristic of the twisted string actuation system [1] has been exploited for this purposes. Figure 3 shows the relation between the joint position, the actuation force and the resulting joint stiffness. The dynamic models as well as a feedback linearization controller for position/force control of the load is reported and validated through simulations. Preliminary experimental results are reported to evaluate the characteristics of the system and the properties of the controller.

<table>
<thead>
<tr>
<th>Twist Angle [rad]</th>
<th>Actuation Length [mm]</th>
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<tbody>
<tr>
<td>0</td>
<td>50.00</td>
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<tr>
<td>4π</td>
<td>48.40</td>
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<tr>
<td>8π</td>
<td>43.37</td>
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<tr>
<td>12π</td>
<td>33.10</td>
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Fig. 1. Basic concept (top) and schematic representation of the twisted string actuation system (bottom).

Fig. 2. Schematic representation of the rotative joint with two twisted string transmission systems.
Fig. 3. Stiffness of the link versus balanced load forces versus load position.

REFERENCES


