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Friction compensation techniques for tendon-driven robotic hands

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ABSTRACT

In this paper, novel methods for friction compensation in tendon-driven robotic hands are presented and discussed. The results of the proposed techniques have been experimentally validated on the DEXMART robotic hand, where the adoption of joints based on sliding pairs (to reduce the complexity of the mechanism and to ease the assembly procedure) introduces as a side effect a non-negligible joint friction. These friction phenomena have been modeled by means of a specialized version of the LuGre model in which the friction coefficients vary with the normal force. After an experimental validation on a specific laboratory setup, a simplified friction model has been derived and used in the joint position control loop of the DEXMART hand to compute a feed-forward term for reducing the position error. A comparison of this approach with other model and non-model based friction compensation techniques is also presented and discussed.

1. Introduction

In the past, the biomimetic approach has succeeded in overcoming many difficult challenges in engineering design, and nowadays it is increasingly applied in robotics to address problems that have proved resistant to conventional engineering solutions, as shown by the explosive growth in biomimetic research [1]. Despite the relevant number of anthropomorphic robotic hand prototypes developed so far, comparing the features exhibited by each design with those of the reference model, the human hand, it is evident that many evolution steps are still necessary and further research effort in the field is fully motivated. In this context, the research activity carried out within the DEXMART project [2–4] is aimed at the development of a “new generation” of robotic hands, see Fig. 1, characterized by a biologically-inspired endoskeletal structure with sliding pairs, a tendon-based transmissions system, an appropriate sensory apparatus, that includes force, tactile and position sensors, integrated into the mechanical structure of the robotic hand, and a soft contact interface mimicking the human skin [5] for improving the distribution of the contact forces and the stability of the grasp. On the other hand, the choice of bio-inspired solutions instead of their “classical” mechanical counterparts implies a fine modeling of each subsystem and the adoption of suitable control algorithms for compensating the side effects of these design choices. This approach is in line with the philosophy of moving the complexity from the time and cost expensive mechanics and electronics to the easy reprogrammable control software design.

Based also on previous works on the identification of both tendon [6] and joint [7] friction, carried out on many robot hand prototypes, the investigation of friction compensation techniques for tendon-driven robotic systems is reported in this paper. This analysis has been applied to the joints of the DEXMART Hand, focusing on both tendon and joint friction modeling, and on the identification of the model parameters. The friction emerging both in the joints and in the tendons shows a nonlinear load dependent behavior. This fact requires the introduction of a recursive algorithm for computing the necessary actuation forces for compensating the friction effects without increasing too much the controller complexity. The experimental activity reported in this paper has been carried out on a simplified system, shown in Fig. 2, composed by one finger of the hand to ease the analysis, focusing only on the friction problem. The joint friction has been firstly identified by means of a specialized version of the LuGre friction model. Then, two approaches have been used to compensate the joint friction. In the first approach, a simplified version of the LuGre friction model used for the friction identification has been adopted. This model has been suitably adapted for reducing the complexity and the computational effort of the control algorithm. In the second case, a non-model-based approach based on a generalized momenta observer has been evaluated and compared with the previous technique. An experimental evaluation of the friction compensation techniques has been carried out, considering also a proper combination of the two approaches.

The paper is structured as follows: Section 2 reports the motivations of this work and a brief overview of the literature about the

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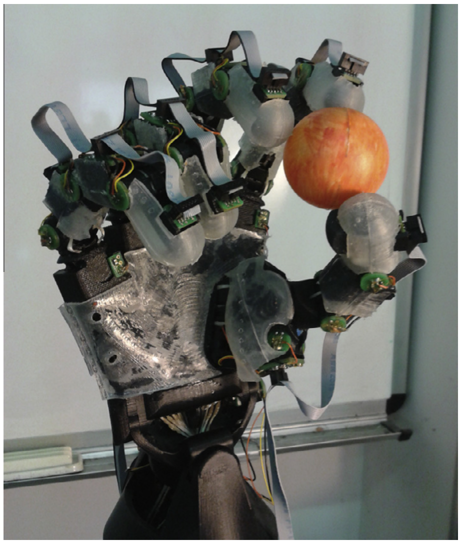

Fig. 1. The DEXMART Hand.

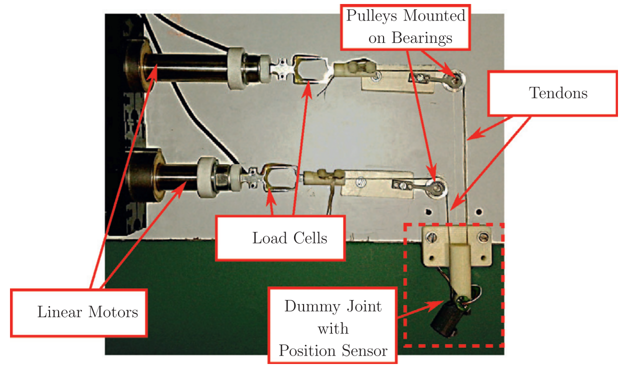

Fig. 3. The experimental setup for joint friction identification.

relevant topics discussed in this paper. Section 3 reports the joint friction model and the experimental verification of the joint friction effects. In Section 4 a brief description of the DEXMART Hand and of the experimental setup used for the validation of the proposed friction compensation techniques is reported, whereas Section 5 addresses the definition of the proposed model and non-model-based friction compensation techniques. Finally, Section 6 shows the results of the experimental evaluation of the proposed techniques and Section 7 reports the conclusions and the future research directions of this work.

2. Motivations and related work

Many robotic hands have been developed and proposed in the literature, focusing on different design aspects like reduction of the number of actuators [8], anthropomorphic aspect [9], very high speed [10] or compliance [11], dexterity potentialities [12–14] or robustness [15] to name a few. Most of the proposed design solutions are based on "classical" approaches, mainly based on non-biologically inspired mechanics, with abundance of gears, pulleys, bearings and similar hardware. These approaches allow developing robotic systems that are relatively simple to control but very difficult and expensive both in the design and in the production phases. Simplification of the mechanical design, the overall costs and the time production have been some of the goals of the DEXMART Hand project. In particular, in the DEXMART Hand, shown in Fig. 1, the simplification of the joint mechanism is obtained by adopting integrated pin joints with sliding profiles, as shown in detail in Fig. 4. This solution allows reducing at minimum the assembly complexity, but introduces non-negligible friction at joint level, that must therefore be compensated by proper control strategies, as discussed in the following sections.

Several model based [16,17] and non-model based [18–20] techniques for friction compensation can be found in literature. While model based techniques rely on the identification of a suitable friction model, non-model based techniques consist in the design of an observer able to estimate the deviation of the system dynamics from its nominal behavior, i.e. without friction, caused by external disturbances, i.e. the friction. The advantage of model based friction compensation is the possibility of a simple feed-forward implementation, that in general does not affect the system stability. However, a drawback is that it usually requires a complex identification phase [6,21,22] and, moreover, its effectiveness is limited by the time and condition variability of friction phenomena. This latter issue can be mitigated by adopting adaptive friction estimation [23], at the expense of implementation complexity and system stability. On the other hand, non-model based compensation does not need the identification of the friction model and parameters, but requires the knowledge of the (nominal) system dynamics. Moreover, system stability is crucial in this case since these techniques are based on the system output (or state) feedback.

In this paper, the identification of the friction phenomena acting at joint level and the experimental evaluation of both model and non-model based compensation techniques for the DEXMART Hand are considered, trying to define a suitable trade-off between the complexity of the identification procedure, the complexity of the robotic hand controller and the performance of the overall system.

3. Joint friction model

The first step toward the implementation of a model based joint friction compensation algorithm is the definition of a suitable friction model and the identification of the relative parameters. According to [24] and because of the sliding contacts, the friction

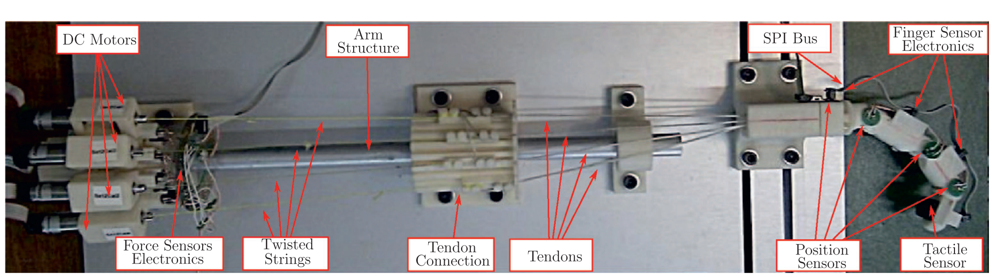

Fig. 2. Detailed view of the finger actuation module.