

# Sensitive Active Surfaces on the Velvet II Dexterous Gripper

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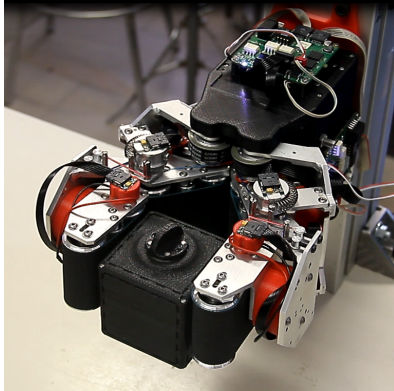


Fig. 1. The Velvet II dexterous gripper developed at the University of Pisa. It comprises two fingers, each of which has two phalanges and a planar manipulator structure with two rotary joints. Furthermore, each phalanx is equipped with one Sensitive Active Surface (SAS).

The Velvet Fingers [1] is a dexterous under-actuated gripper for unstructured industrial environments. It offers enhanced manipulability by means of Active Surfaces (AS) on its fingers, *i. e.*, surfaces able to emulate different levels of friction and to apply tangential thrusts to the contacted object. The usefulness of the AS (implemented by controlled conveyor belts) is discussed in [2]. Although their benefits are substantial, their main limitations are the lack of force feedback and missing information of the contact point location, as well as limitations on the fictitious friction range.

In this article we discuss the employment of an intrinsic force/torque (F/T) sensor mounted between the frame of the phalanx and the AS which are henceforth referred to as Sensitive Active Surfaces (SAS). For this purpose the experimental device shown and described in Fig. 2 has been set up at the University of Pisa. Furthermore, we implemented and tested an algorithm for the determination of contact point locations, as well as a variable friction control algorithm.

The geometrical portion of the belt involved in a possible contact with a grasped object is formed by a plane corresponding to the outer conveyor belt surface and two semicircles associated with the belt rollers (see indicators (3), (4) and (8) in Fig. 2). Since the sensing surface is convex, the

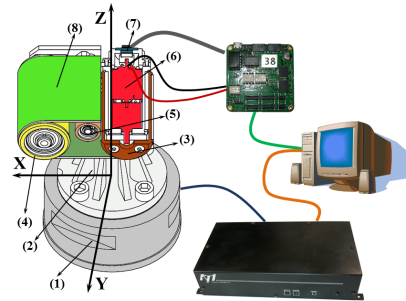


Fig. 2. The experimental set up formed by a small conveyor belt mounted on an ATI-Gamma F/T transducer (1) by means of the interface (2). The belt (8) winds around a driver cylinder (3) and a driven cylinder (4). A central idle roll (5) supports the belt on the upper side. An AS5045 Austriamicrosystem magnetic encoder (7) reads the angular position of the motor shaft. The actuator (6), mounted inside the driver roll, is a 4.5W Maxon RE-MAX brushed DC motor with a 84:1 gear-head.

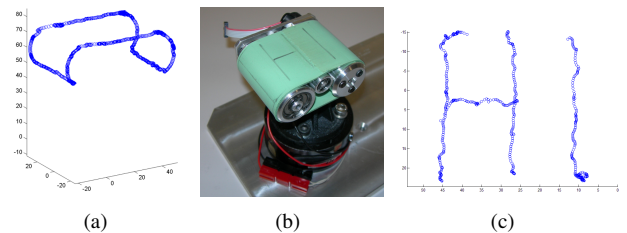


Fig. 3. (a) the reconstructed border of the belt obtained from the sensor readings collected while tracking the border with a tipped object; (b) the greeting "HI" was drawn on a belt with a ruler; (c) the reconstructed trajectory obtained by manually tracking the text with a tipped object.

contact point location and the corresponding applied wrench can always be computed from the F/T sensor readings [3]. This algorithm allows to detect the center of pressure on the SAS and the corresponding external wrench caused by grasping an object. Several examples are illustrated in Fig. 3.

The employment of a F/T transducer also allows to substantially improve the variable friction concept [4] implemented in the Velvet Fingers [2]. This is due to two reasons: first, by knowing the normal component of the external force acting on the surface it is possible to emulate the friction coefficient as the ratio between the tangential force and the normal force. Second, knowledge of the tangential force direction allows to compensate for the internal friction of the physical implementation of the SAS. Assuming that the voltage  $V^*$  which is necessary to put the motor in incipient movement is known, the motor voltage corresponding to a desired friction coefficient  $\mu^*$  can be expressed by simply

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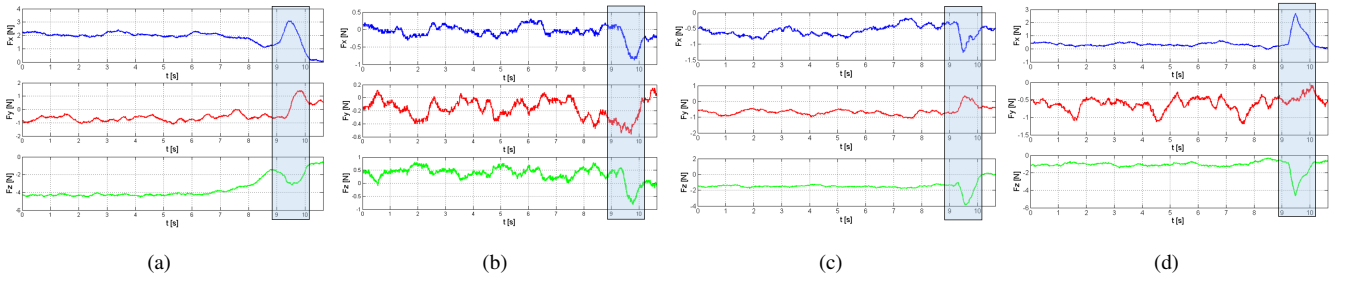


Fig. 4. Sliding experiments of a grasped battery. Every graph is relative to a phalanx of the gripper and in every graph the  $F_x$ ,  $F_y$ ,  $F_z$  components are shown. In the pale blue rectangles the redistribution of the forces is clearly evident.

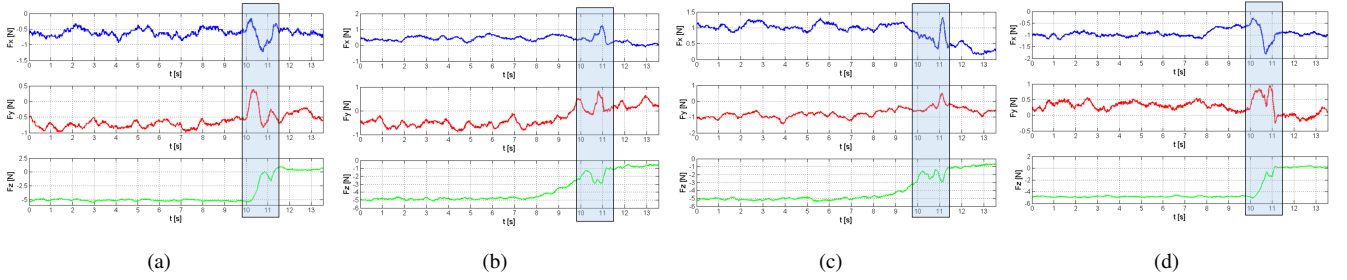


Fig. 5. Sliding experiments of a grasped hammer. Every graph is relative to a phalanx of the gripper and in every graph the  $F_x$ ,  $F_y$ ,  $F_z$  components are shown. The pale blue rectangles highlight the force redistribution in the pre-sliding phase.

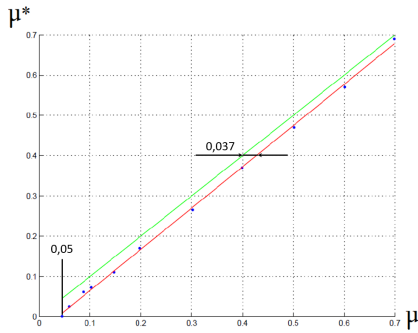


Fig. 6. Graph illustrating the error occurred in the friction coefficient simulation. The red line is the linear interpolation of the evaluated effective friction coefficient and the green line is the bisector of the quadrant.

superimposing  $V^*$  and the voltage from the Hayward algorithm  $V_H$ :

$$V = V^* - V_H = V^* - \frac{Rr}{k_\tau \tau} SAT_{-\mu^* F_N}^{\mu^* F_N} k_s \Delta \theta. \quad (1)$$

In Fig. 6 the desired friction coefficient  $\mu^*$  is compared to the effective friction coefficient  $\mu$  (the red line is the interpolating line of the experimentally evaluated effective friction coefficient). The graph makes two important aspects evident: first, the friction coefficient can be tuned to a very low level (up to approximately 0.05). Second, the interpolating line has an horizontal offset of 0.037 with respect to the bisector  $\mu = \mu^*$  (the green line) which represents the perfect match between  $\mu$  and  $\mu^*$  and this is due to the difficulty of exactly compensating the internal friction.

The four SAS of the Velvet II (see Fig. 1) are implemented by fitting custom made F/T sensors to the conveyor belt

modules used in the previously described experiments. In a final set of experiments, we used the SAS in a preliminary investigation of the contact forces occurring in incipient slippage conditions. Gunji et al. [5] observed a significant decrease of the grasping force (detected by a tactile sensor) immediately before the slip displacement of a pinch grasped object. Our experiments have been conducted in power grasp configurations by slowly decreasing the internal grasp force until the grasped object slipped. As shown in Fig. 4 and Fig. 5, which refer to the grasping of a battery and an hammer, dropping the object is predated by a rapid redistribution of the components of the total grasping forces on each phalanx of the gripper, highlighted in the graphs with rectangles.

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