Linear bristle actuators for robotics

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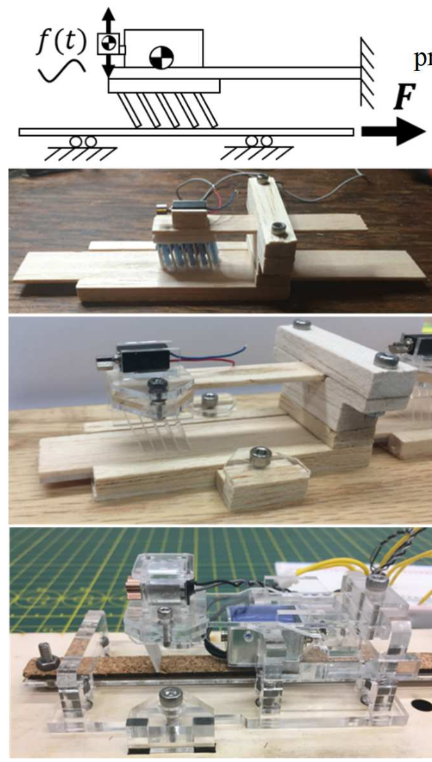
I. Introduction

Vibration powered mobile robots have been demonstrated and studied at various scales for their extreme simplicity [1], dynamic behavior [2], as well as amenability to replication in large numbers particularly well suited for research in swarm robotics [3]. The most common implementation of this type of robot is known informally as the "bristle bot", typically built from a repurposed toothbrush head, a small vibration motor, and a coin cell battery. The low-tech, low-cost fabrication of these relatively high speed and seemingly chaotic devices have made bristle bots a popular hands-on STEAM educational outreach activity for children, while simultaneously attracting the attention of academic researchers and engineers at high-level institutions that have studied, modeled, and simulated their behavior through experimental and mathematical frameworks [4].

While bristle bots been shown at both macro and micro [5] scales, it has nearly always been used for the same purpose, in untethered, mobile robots. In this work we will demonstrate a new way to use the bristle bot concept in an inverted sense; harnessing the force of vibration not for locomotion but for linear actuation and demonstrate the principle on rapidly fabricated hardware prototypes. Other work has studied bristle based force generation on a fixed test setup [6], or utilized high-frequency actuation in piezoelectric driven linear actuators for nano and micro-positioning and similar scale forces, but such devices require precise timing and activation of successive piezo actuators quite different from the operating principle of bristle bot force generation (highly stochastic). We will show the first example of a self-contained macro scale linear actuator based on the simple bristle-based vibratory force transmission.

II. Concept prototype

A first prototype linear vibration actuator was initially created from a balsa wood frame and the same components used to fabricate a typical bristle bot – a small eccentric mass vibration motor and an off-the-shelf toothbrush head. The design of the actuator consisted of a cantilevered beam which held the toothbrush head as well as the vibration motor at the distal end, allowing it to vibrate freely on the flexible beam while constrained from driving itself away. The bristles of the brush head were held by the elastic cantilevered beam in contact with a sliding 'tendon' component, which is a rigid, flat element guided by a low-friction track and constrained to only one linear degree of freedom, inline with the vibrating toothbrush head. The chosen toothbrush head featured bristles angled in a particular direction, sloping inward toward the direction of the fixed end of the cantilevered beam. When the vibration motor is activated, the angled bristles leverage an anisotropic friction effect that drives the tendon below in linear translation.



Once this first prototype proved that the concept would work a second prototype linear actuator was fabricated from laser cut acrylic and plywood materials to more carefully experimentally study the effects of different design parameters on the performance of the linear actuator, such as bristle angle, number, and stiffness, as well as demonstrate the effects of actuator grouping (multiple drive units in series). A modular platform was constructed to allow several actuator heads to drive a common tendon, and to test different types of drive units. While the first prototypes featured a fixed brush which was always in contact with the output tendon, this did not allow the tendon to be backdriven or move passively without feeling impedance from bristle friction. The solution was to create a different type of actuator drive unit with a clutch which allowed the bristle head to be actively engaged or disengaged with the sliding tendon. A simple clutch was realized using a linear solenoid actuator to deflect a flexible beam initially holding the vibrating brush head offset from contact with the tendon surface.

References

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