MaTBot: A Magneto-adhesive Track roBot for the inspection of artificial smooth substrates

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Abstract: This paper introduces the small sized tracked climbing robot *MaTBot*. Due to the combination of different adhesion principles, a bio-inspired micropatterned adhesive tape and a permanent magnet, we designed the robot capable of climbing up smooth (flat) artificial substrates. For the purpose of the novel contact mechanism, a laminated track was manufactured. The robot can climb up; the angles of slope are below 60° on glass substrates solely using the adhesive tape and up to 90° on ferromagnetic substrates by additional employing the magnetic adhesion principle. The robot has a size of 60 mm · 60 mm · 16 mm, its weight is less than 60 g. The maximum of velocity averages 6.9 cm/s. Due to the used passive adhesion principles, a rather long period of application is achieved.

Keywords: Bio-inspired adhesion principle, magnetic adhesion principle, small sized climbing robots

1. INTRODUCTION

The miniaturization of climbing robots and the resulting decrease of their weights enables the implementation and investigation of various adhesion principles and their combination. Mainly derived from the results of biological research on adhesion mechanisms the small-sized climbing robot *MaTBot* is designed. In addition to the latest state of the art concerning small sized climbing robots with passive adhesion principles [1, 5, 7, 9, 10], *MaTBot* employs a combination of two adhesion principles: 1) a bio-inspired dry adhesion principle using a new generation of a micropatterned dry adhesive tape and 2) a magnetic principle utilizing effect of permanent magnetization.

Possible areas of application are inspection and maintenance of smooth artificial structures e.g. surfaces of solar cells, glass facades, ship hulls, pipes, tanks, etc.

2. ADHESION PRINCIPLES

Inspired by the functional morphology of tarsal hairs of male Chrysomelidae beetles [3, 6] a bio-inspired micropatterned elastomer tape with enhanced adhesion compared to a smooth control made of the same material is employed to produce dry adhesion.

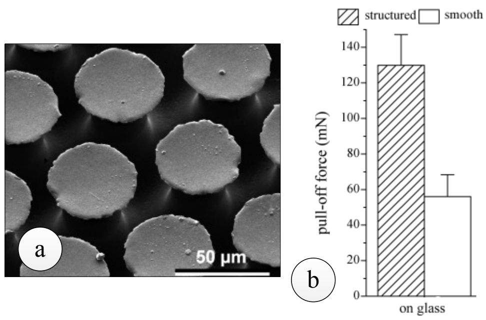

Fig. 1: a) SEM micrograph showing bio-inspired micropatterned adhesive tape with an about twice higher adhesion compared to a smooth control of the same material (b) measured in a flat-on-flat contact scheme [3, 6].

Enhanced adhesive capability of this tape was shown to be a combination of intermolecular Van der Waals forces and particular mushroom-like crack-trapping geometry. Adhesion in normal direction of about 4.1 N/cm^2 was previously reported [3, 6].

The magnetic adhesion principle relies on tiny NdFeB permanent magnets having dimensions of 2.85 mm · 2.85 mm · 0.5 mm. The force of a single magnet averages 0.78 N. Both adhesion principles enable to maintain contact without the consumption of energy.

3. DESIGN OF MATBOT

3.1 Design and manufacturing of the robot

The design of *MaTBot* follows the guideline for mechatronic development VDI 2206. The required torque for locomotion is generated by two servo drives (BMS-Bluebird 303, torque of about 70 Nmm at 4.8 V). With respect to the low center of mass, a self-made drive gear is used. Therewith a secure transmission of the driving torque from servo drives to tracks was obtained.

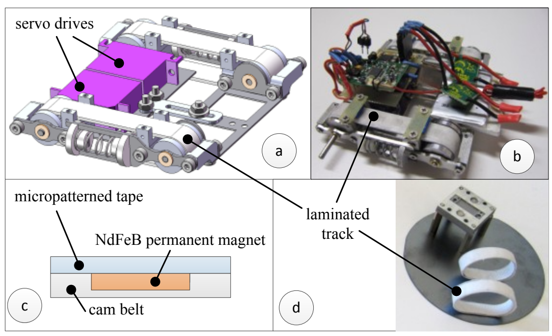

Fig. 2: a) CAD drawing and b) prototype of *MaTBot*, c, d) principle (c) and prototype (d) of the laminated track, respectively

The base frame of *MaTBot* is made of 0.5 mm stainless steel. It also carries the energy supply and the control unit. *MaTBot* is an open-loop remote controlled device at 35.030 MHz.

3.2 Design and manufacturing of the laminated track

Figure 2c, d) displays the structure of the laminated track of *MaTBot*. The first layer resembles a cam belt. It enables force transmission between drive gear and track. The NdFeB permanent magnets compose the second layer, whereas the third layer consists of the micropatterned tape.

Manufacturing process has three steps: 1) molding the cam belt using silicone elastomer WM 372 (Weißmetall Inc., Wuppertal, Germany) 2) insertion of NdFeB permanent magnets into the belt 3) bonding of the micropatterned tape to the belt using two-component silicone elastomer. Due to this bonding process, magnets are completely embedded inside the track. However, apparent contact area between substrate and tracks averages 6.40 cm^2.

4. EXPERIMENTS

4.1 Preparation and experiments

In order to evaluate the performance of *MaTBot* on various inclines of flat glass and ferromagnetic substrates, experiments include the measurement of speed and the period of application. For reproducible and consistent conditions during experiments a purpose-built testing area was designed. It enables the setting of the slope angle of the substrate.

4.2 Results

Current experimental results are summarized in table 1 and 2.

Table 1: The *MaTBot* performance

investigated feature	experimental results
climbing abilities	presently 0-60° (common window glass) and 0-90° (ferromagnetic material)
maneuverability	Good due to separately controlled tracks

Table 2: Climbing abilities of *MaTBot* on common window glass. (*) = result is mean value out of five measurements. Cleaning of substrate and tracks was performed before each run, temperature during measurement: 24 °C, humidity 30 %
(++) = Tracks are equipped without micropatterned tape due to tiny angle of slope

Mean value of	angle of slope			
	0° (*) (++)	20° (*) (++)	40° (*)	60° (*)
speed (cm/s)	6.9	5.8	5.5	4.9
period of application (min.sec)	28.16	27.47	23.40	no long-time measurement due to failure of power amplifiers
max. travelled distance (in m)	≈ 117	≈ 97	≈ 78	

The experiments demonstrated the general advantage of the use of the laminated track. The achieved slope angle was about 60° just due to the contribution of dry adhesion. During all experiments *MaTBot* has demonstrated a very good maneuverability. The period of application averaged between 28 and 24 minutes travelled distance during this time ranged between 117 and 78 meter (line movement, length of the robot: 0.06 meter).

Novel modifications of bio-inspired silicone foils will improve the robot performance in the future: Possible constructional modifications of the robot, such as implementation of wider tracks or a tail like structure, might additionally contribute to stronger adhesion on smooth glass.

5. CONCLUSIONS

The combination of two adhesion principles was implemented into the small-sized climbing robot *MaTBot*. Equipped with laminated tracks, the robot is capable of moving over smooth inclined substrates made of different materials. Experiments have also illustrated long travelling distances of the robot together with the good maneuverability and fast locomotion speed.

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