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Making Orthogonal Transitions with Climbing Mini-Whegs™

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Insects and geckos use claws and adhesive pads to negotiate both rough and smooth surfaces [1][2][3]. Climbing robots have been designed to mimic various aspects of these and other biological systems to operate in specific vertical environments. Robots that adhere to the surface through suction cups [4][5][6], magnetic end-effectors [7][8][9], or adhesive pads [10][11][12][13] can climb featureless, flat, or smoothly curved surfaces. Vortex-generating climbers [14][15] do not require smooth surfaces. Robots have been designed with end-effectors that match specific features of the environment, such as peg-holes [16], handrails [17], climbing-wall footholds[18], and poles [19]. Robots have also been fitted with insect-inspired spines [20][21] to scale rough vertical surfaces.

The Biologically Inspired Robotics Laboratory at Case Western Reserve University has developed an array of miniature remote-controlled climbing vehicles known as Climbing Mini-Whegs™. The key design feature of these robots is the use of multi-spoked wheel-legs, which provide the simplicity and speed of wheels and the maneuverability of legs. In addition, their compliant feet attach and detach from the substrate in an animal inspired manner. They peel from smooth surfaces, requiring less torque from the drive motor than if the feet were lifted all at once.

The first version of these robots used Scotch brand adhesive tape for feet. The combination of flexibility and adhesion properties of the tape was effective for use in multiple test scenarios. Other versions have used feet equipped with sharp spines to climb rough and porous surfaces up to a 60 degree angle.

The ability for robots to cross terrain that is irregular is important. Cockroaches utilize body flexion when climbing over irregular terrain, such as a transition from a vertical to a horizontal surface. To navigate these types of transitions, the body joints have been explored for use on Climbing Mini-Whegs™. See Fig. 1. Ground walking Whegs™ robots have demonstrated that a body joint greatly assists in negotiating tall obstacles. In climbing, a body joint helps the robot make transitions between orthogonal surfaces. This maneuver is accomplished in several main steps. First, the robot drives forward until the front wheel-legs move past the point of transition while the body joint remains straight. Next, the body joint flexes downward until the front wheel-legs touch the top surface. Once they are attached, the middle wheel-legs are placed on the top surface. Finally, the body joint straightens so that the rear wheel-legs detach from the previous surface. The robot then drives forward until it is completely on the top surface. It was found that a single axis body joint placed in line with the middle drive axle is effective in allowing exterior transitions. The tape feet are normally attached to the hubs so that they contact the surface when they are nearly tangential to the surface. For downward transitions, performance is improved when the middle pair of wheel-legs are configured so that the tape protrudes radially from the hub. This allows the tape on the middle feet to adhere to the downward vertical surface sooner, achieving greater stability.

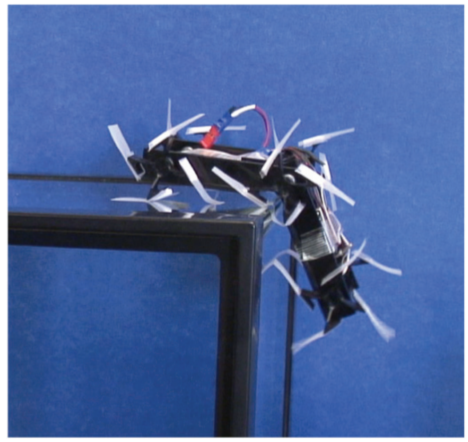

Fig. 1. Climbing Mini-Whegs™ using a body joint

Future adhesives may be even more effective as feet for Climbing Mini-Whegs™. A polymer, polyvinylsiloxane, or PVS, exhibits a much smaller adhesive force than office tape, but can be molded to mimic the adhesive characteristics of animal feet. These PVS samples have tiny molded structures that resemble the micro hairs, or setae, found on geckos and some insects. In addition, this material lasts twice as long as Scotch tape before cleaning is required due to contamination. Because of the relatively small adhesive strength of this structured material, a long tail was added to Climbing Mini-Whegs™ to counter-act the tendency for the robot to flip backwards off the wall. A newer version of the robot, Climbing Mini-Whegs™ XL, has been designed specifically to use weak adhesives on vertical surfaces. The longer body length relative to spoke length provides a longer lever arm to support the moment of the weight, and reduces the tendency to pitch backwards. This design uses six spokes per wheel-leg instead of four, which allows the feet to be shorter, and thus stiffer. Note that the PVS feet used for this robot are unstructured, meaning that they do not contain micro hair structure. Even using unstructured PVS, this robot was able to climb 330 centimeters before requiring cleaning.

See the companion paper for more detailed analysis:

Daltorio, K. A., Witushynsky, T. C., Wile, G. D., Palmer, L. R., Malek, A. A., Ahmad, M. R., Southard, L., Gorb, S. N., Ritzmann, R. E., Quinn, R. D., "A Body Joint Improves Vertical to Horizontal Transitions
of a Wall-Climbing Robot," in *Proc. of IEEE/RSJ Int. Conf. on Robotics and Automation (ICRA)*, 2008.

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