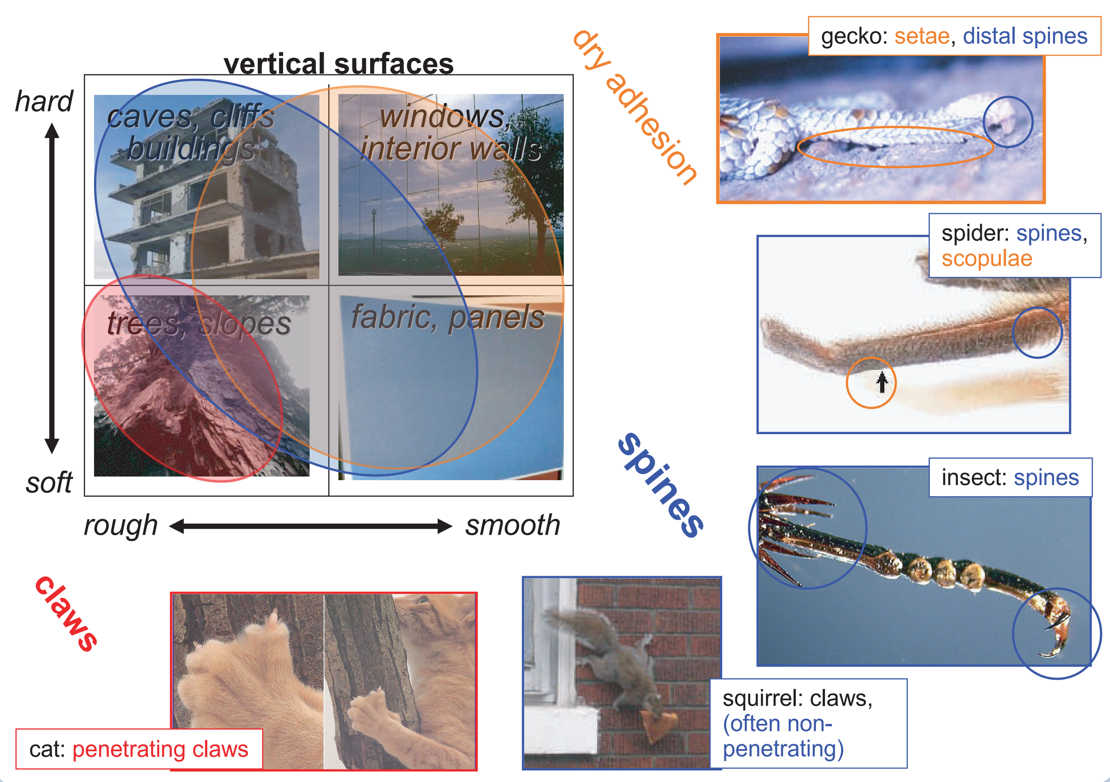
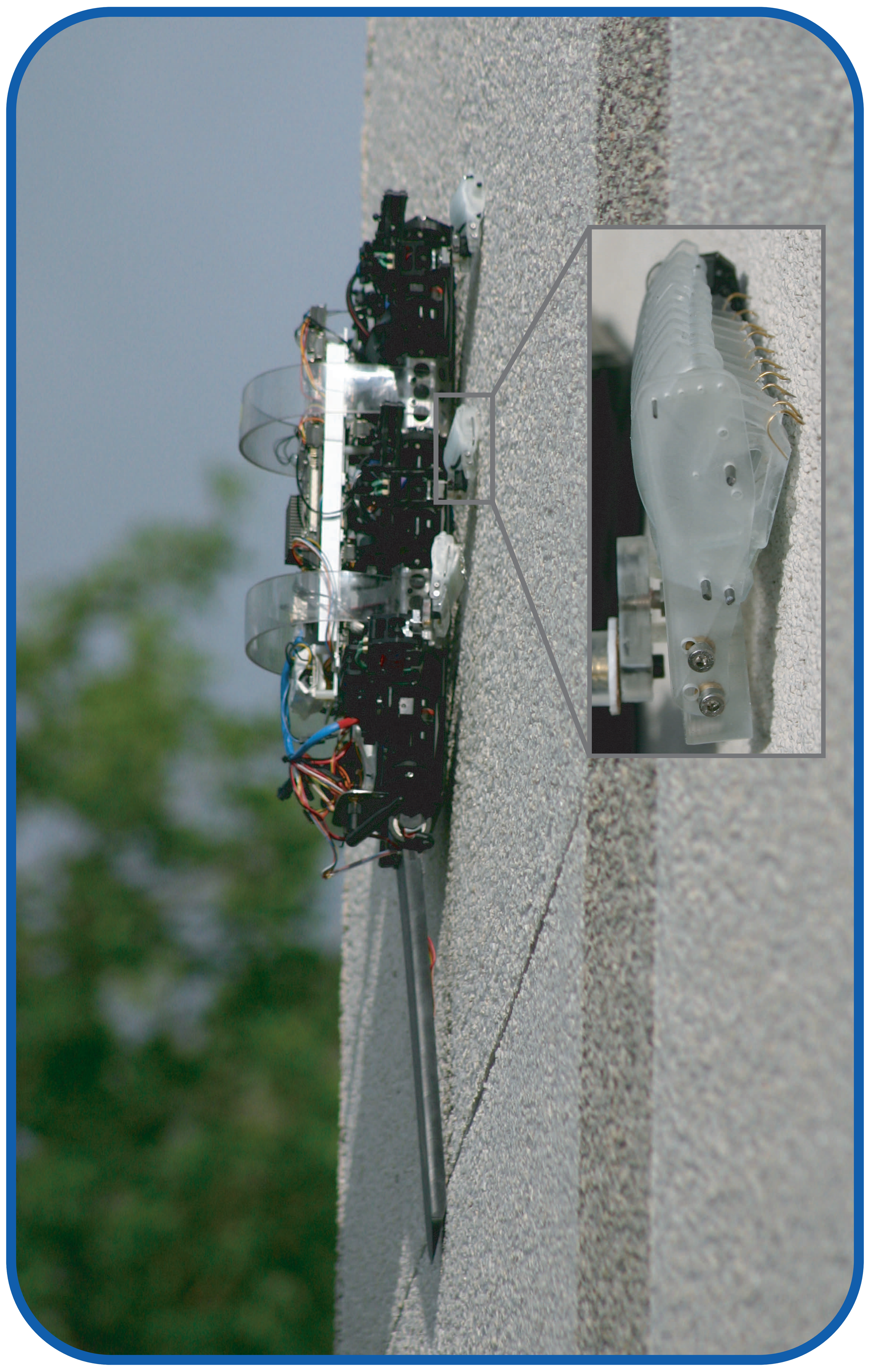
Climbing Walls with Microspines

A.T. Asbeck, S. Kim, A. McClung, A. Parness and M.R. Cutkosky
Stanford University, Dept. of Mechanical Engineering

Climbing with spines in Nature

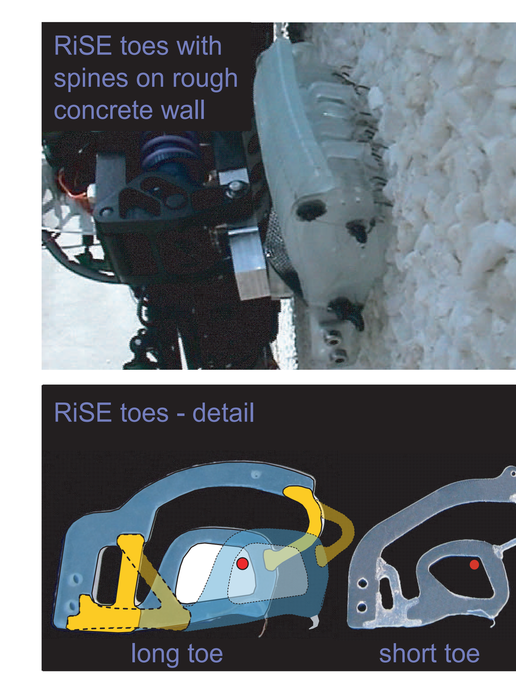




Scaling spines from Spinybot to RiSE

Adaptations:

- Foot width increased, length decreased to avoid interference
- Spine count increased
- Toes redesigned with tougher materials, stronger spines
- Compliances in normal, tangential directions adapted for higher load, different stroke length
- Overload-release mechanism reduces spine damage
- Heterogeneous spine/toe population for wide range of surfaces



● = pin for overload protection

Climbing buildings with μspines

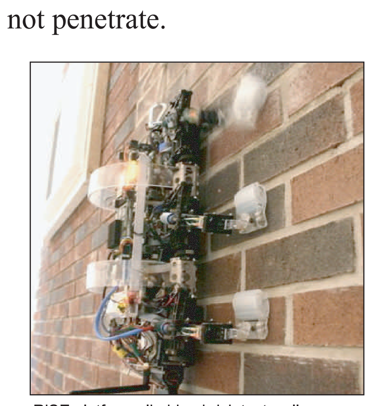
RiSE platform climbing library at SwRI, San Antonio, TX

Advantages

- **Low power**:
  - Requires little force to engage or disengage
  - Robot can hang for extended periods without consuming power or making noise
- Works on a **wide range of outdoor building surfaces** (roughness ≥ #120 grit sandpaper)
- Unaffected by modest amounts of **dirt or moisture**
- Leaves no footprints and **will not damage** hard surfaces because spines do not penetrate.

Limitations

- Cannot be used on glass or similarly smooth surfaces.
- Sensitive to surface normal distribution (works less well on surfaces with smooth bumps or pits).
- Payload is low on weak or soft surfaces (e.g. cork, adobe) because spines do not penetrate.
- Wear occurs on abrasive surfaces (e.g., spines can become dull after a few days on concrete).



RiSE platform climbing brick test wall

Spines for heavy robots

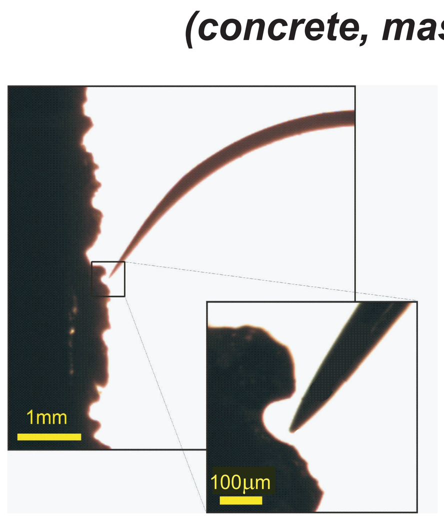
Effect of Scaling Parameters on Toe Compliances

Stiffness (k_{ij})	*X* stiffness	*Y* stiffness
Toes per foot *N*	$\propto 1/N$	$\propto 1/N$
Robot mass *M*	constant	$\propto M$
Spine tip radius r_s	constant	$\propto 1/r_s$

X elastic members (3.) buckle to minimize engagement force in -X direction. Required X stiffness is independent of robot mass and spine size. Stiffness per toe varies with number of toes.
Y elastic members (1.), (2.) stretch to promote load sharing. Y stiffness depends on robot mass. Larger spines require a longer stretch (low k) to find asperities. Number of toes varies as $N \propto 1/r_s$ for a constant robot mass, assuming the spine dimensions are proportional to the tip radius r_s.

Spine scaling for hard surfaces

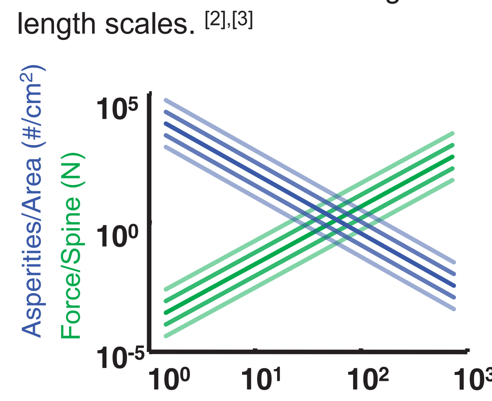
(concrete, masonry, rock, stucco)



Spines catch on asperities (bumps or pits) on surfaces.

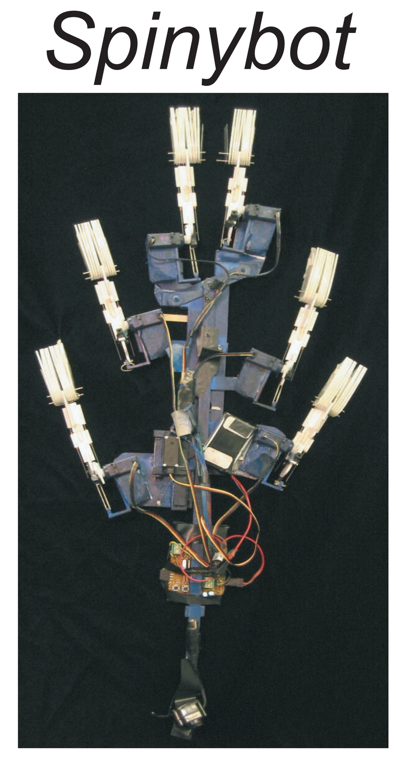
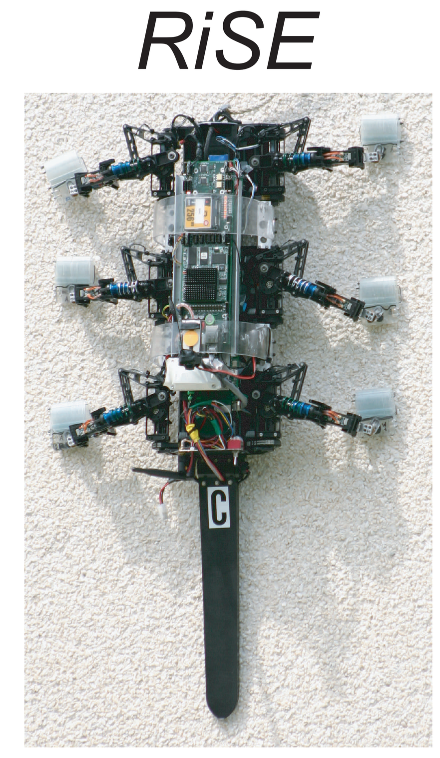
For effective engagement, we require that $r_s < r_a$, where r_s is the spine tip radius and r_a is the average asperity radius. [1]

Since many surfaces are approximately fractal in nature, spines can be used over a wide range of length scales. [2],[3]



Let λ = length scale

- **--- *fractal* surface ⇒ asperities per unit area $\propto 1/\lambda^2$**
- **--- spine/claw strength $\propto \lambda^2$**

Spinybot	RiSE
	

Common features facilitating climbing

Long tail prevents pitching back
Sprawled posture, COM close to wall
Legs pull inward slightly
COM well within polygon of wall contacts—very stable

Surfaces able to climb

Spinybot	RiSE
Stucco	Stucco
Brick	Brick
Concrete	Concrete
	Wood planks
	Trees
	Chain-link fence

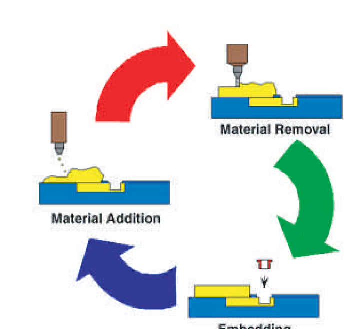
Mechanical Design

Spinybot	RiSE
Alternating tripod motion – fixed servo pattern	2 DOF/leg: wing and crank 4-bar linkage
3 Controlled DOF	
Body-level load sharing via mechanical compliance	Body-level load sharing via force sensors and active control
Balsa frame	Aluminum frame
PIC microprocessor	Pentium computer

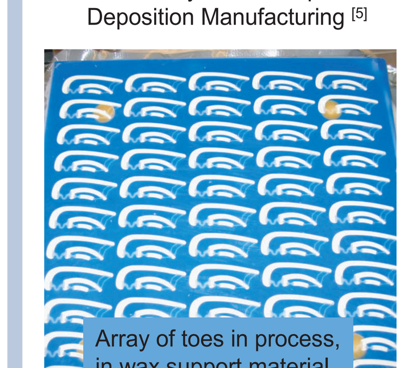
Stats

Spinybot	RiSE
Mass: 400g	Mass: 3kg
Max. payload: 400g	Max. payload: 1.5kg
Speed: 2.3 cm/sec	Speed: 1.5 cm/sec

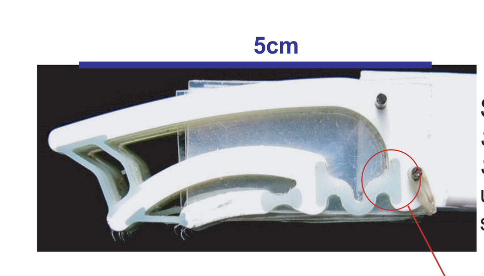
Fabricating compliant spined toes



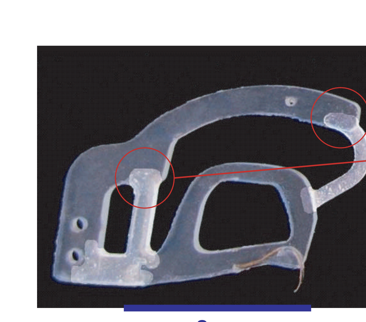
Process cycle for Shape Deposition Manufacturing [5]



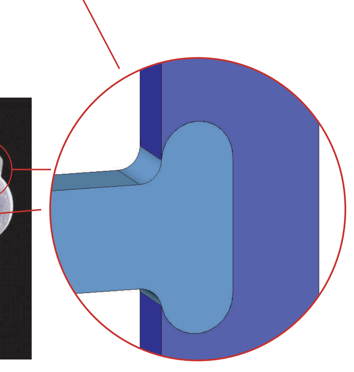
Array of toes in process, in wax support material



Spinybot toe: *Shore 75D* (white) *Shore 20A* (gray) urethanes + embedded stainless steel spines



RiSE toe: *Shore 80D* (dark gray), *Shore 55A* (light gray) urethanes + embedded steel spine



Detail of soft/hard material junction for improved fatigue life

Design requirements for feet and toes

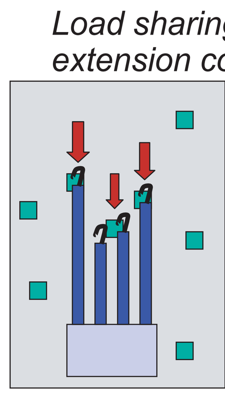
Masonry surfaces:

- have many small asperities per unit area,
- requiring small (r_s < 20 μm) spines,
- with small (f < 0.2N) loads per spine.

Therefore the foot must:

- ensure that many spines independently attach to asperities,
- promote load-sharing among spines. [3],[4]

Load sharing through extension compliance



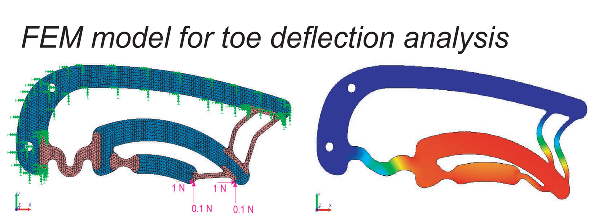
■ = Asperity
↓ = Load on attached toe

Spined toes on smooth concrete wall

Each toe is a compliant, multi-bar linkage designed to:

- **increase probability that spines will catch asperities,**
- **assume a share of the load,**
- **avoid premature slip-off.**

FEM model for toe deflection analysis



Acknowledgements

RiSE Consortium Members

RiSE is funded by

DARPA/SPAWAR N66001-03-C-8045

With additional support from the Intelligence Community Postdoctoral Fellowship Program

References

[1] Z.D. Dai, S.N. Gorb, and U. Schwarz. "Roughness-dependent friction force of the tarsal claw system in the beetle pachnoda marginata (coleoptera, scarabaeidae)." *J. of Exp. Bio.*, vol. 205, no.16, pp.2479–2488, 2002.
[2] J. A. Greenwood, "Contact of rough surfaces." in *Fundamentals of Friction: Macroscopic and Microscopic Processes*, I. L. Singer and H. M. Pollock, Eds. Kluwer, Dordrecht, pp. 37-56, 1992a.
[3] A.T. Asbeck, S. Kim, W.R. Provancher, M.R. Cutkosky, and M. Lanzetta, "Scaling Hard Vertical Surfaces with Compliant Microspine Arrays," in *Proc., Robotics Science and Systems Conf.*, Cambridge, MA, June 2005.
[4] S. Kim, A.T. Asbeck, M.R. Cutkosky, and W.R. Provancher, "Spinybot: Climbing Hard Walls with Compliant Microspines," in *Proc., International Conf. on Advanced Robotics*, Seattle, WA, July, 2005.
[5] L.E. Weiss, *et al.*, "Shape Deposition Manufacturing of Heterogenous Structures," *J. of Manufacturing Sys.*, vol.16, no.4, pp.239-248, 1997.