

# StickyBricks: An Adhesion-Based Modular Reconfigurable Robotic System

Eric Schweikardt  
 Computational Design Laboratory  
 Carnegie Mellon University, Pittsburgh, PA 15213  
 tza@cmu.edu

**Abstract--** The field of modular robotics depends predominantly on the scale and reliability of both actuation and inter-module connection. This paper presents StickyBricks, a unique modular robotic system comprised of 20mm squares with adhesive belts around their perimeter. The dynamics of a multiple belt-drive system and the unique motion constraints imposed by such a system are examined. Several methods of adhesion are discussed, and a future view incorporating gecko-inspired dry adhesives, 3D locomotion, and sensing capability is addressed.

## I. INTRODUCTION

The idea of fine-grained modular self-reconfigurable robots is compelling. One can imagine large numbers of tiny robotic modules working together to create larger robots. In contrast to large, expensive and complex robots, self-reconfigurable systems present the idea of a crate of identical modules which can be programmed to arrange themselves in multiple configurations for multiple tasks.

Mark Yim [3] describes three benefits of modular self-reconfigurables: reliability, versatility, and cost. While large robots created for a specific task are often suited only to that task, reconfigurable robots are able to adapt to different tasks in different environments. Large custom-made robots are always expensive, and often unreliable, while small modules can be mass-produced for vast cost savings.

Most of the extant designs are based on homogeneous modules; systems of identical components which connect with each other to form lattice-like assemblies. Current designs feature either modules which push and pull their neighbors [2] or which rotate around each other [1].

A primary point of failure of existing designs lies in the reliability of the inter-module connections, which are either mechanical or magnetic. The goal for this project is to explore the feasibility of a belt-drive design using adhesion to connect modules to one another. Figures 1

and 2 show the first design for a StickyBrick module.

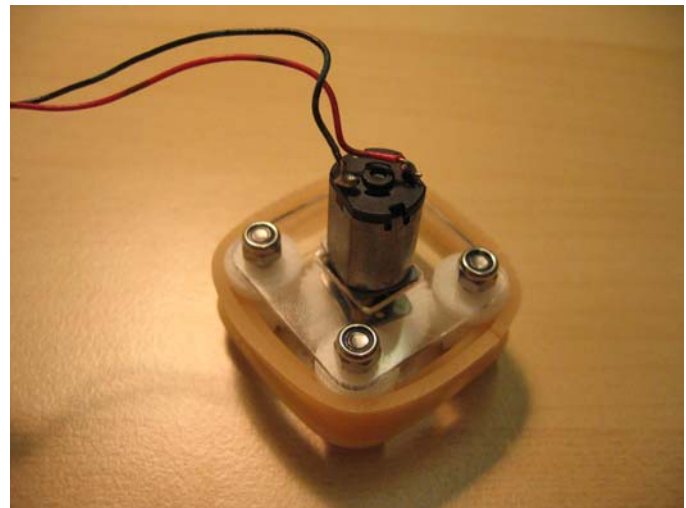


Figure 1: A single 20mm StickyBrick module

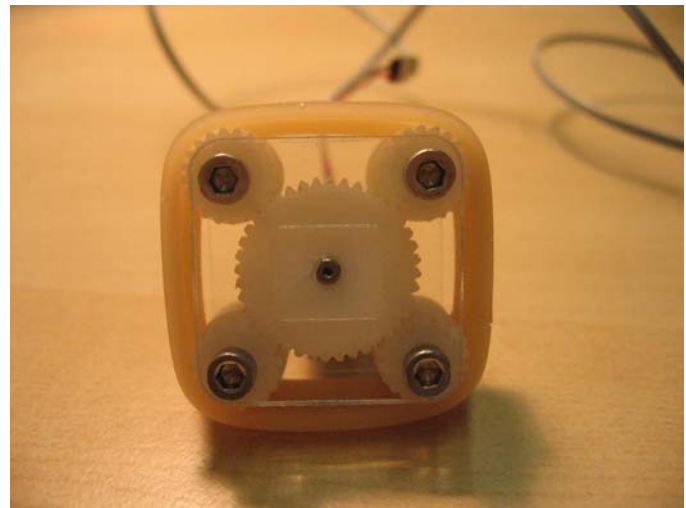


Figure 2: Bottom view of a StickyBrick

## II. BELT-DRIVE LOCOMOTION

In order to experiment with belt-drive locomotion, a fixed system is assumed, with one or more modules moving along the perimeter of the system. Motion along a linear edge of the system is straightforward, but the singularities involved in concave and convex transitions

demand analysis.

Without experimentation, it is unclear exactly how a StickyBrick will handle a convexity (figure 3), but there are no forces present to cause it to detach from the structure or reverse direction. A concavity is another matter. Upon approaching a concavity, a StickyBrick will adhere to the perpendicular surface (figure 4) and will attempt to continue and detach from the previous surface. To accomplish the transition, it will be necessary for the shear force of the belt against the new surface to be greater than the adhesion force normal to the previous surface.

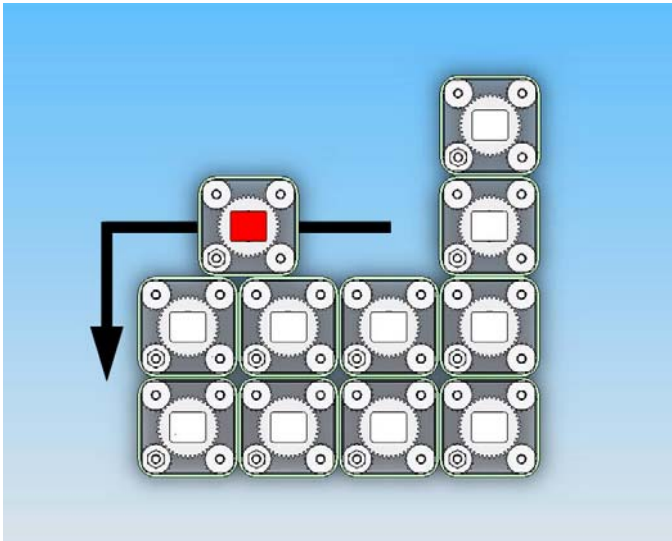


Figure 3: Navigating a convexity

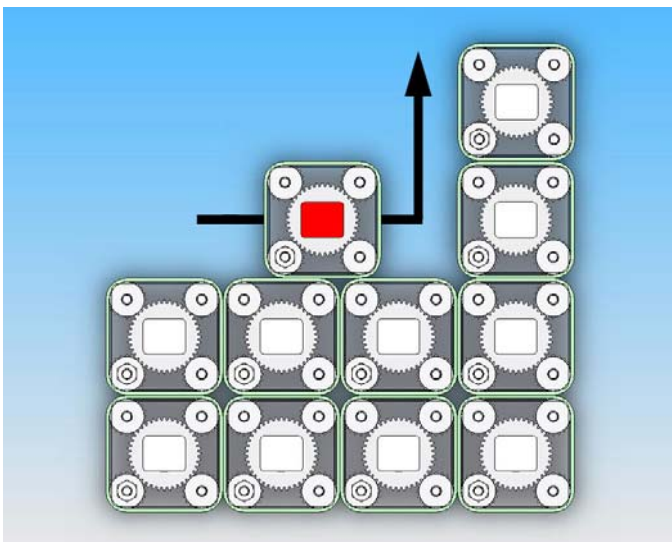


Figure 4: Navigating a concavity

A serious limitation of a belt-drive system for modular robotics is its inherent 2D nature. While true of the current StickyBrick design, one can imagine designs based on spherical belts, or systems which activate a

second belt for motion in the third dimension.

As individual StickyBricks are only 20mm square, very little torque is required to move them along the edge of an assembly. The torque generated by electric motors scales down poorly, however, and advances in dry adhesive technology would increase the force necessary to peel the adhesive belt from the connected assembly. Required actuator torque is specified by:

$$\tau_a \geq W_{SB} + F_p \quad (1)$$

where

$\tau_a$  Actuator torque

$W_{SB}$  Weight of one StickyBrick

$F_p$  Adhesive peel force

The nature of belt-drive locomotion is very different from a standard “box on wheels” mobile cube. Since the side of a StickyBrick opposite the drive side is always moving in an opposite direction from travel, a StickyBrick module can carry no payload, or piggyback other modules. In contrast to most other modular systems [2][3][9] which rely on an assembly of modules (a meta-module) to move, StickyBricks move in a necessarily independent fashion.

The continuous belt rotation creates many situations in which an individual module cannot move (Figure 5). Although this restricts motion planning, it also may serve to strengthen the lattice-like assembly of modules. In general, an assembly of StickyBricks must begin to reconfigure at the corners, as any brick attached on two of its opposite edges is free to move.

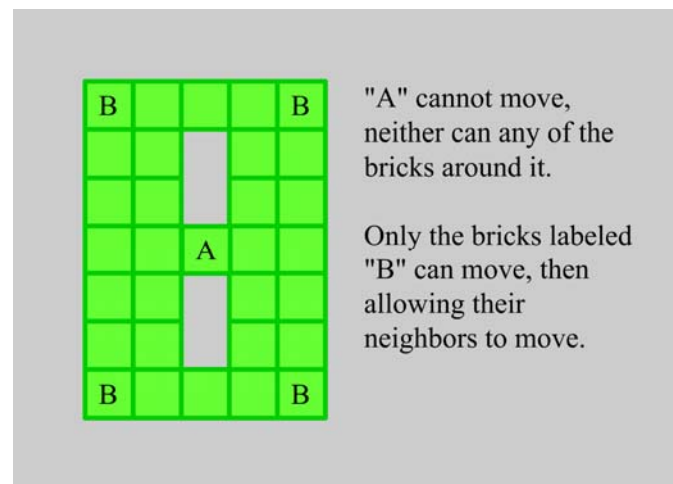


Figure 5: Motion Planning Constraints

### III. ADHESION

The success of the StickyBrick system will depend on

the adhesion properties of the individual modules to one another. Force measurements will be conducted on various polymers to determine their suitability for use as drive belts. Three forces will be measured for each material's adhesion to itself: adhesion force along the normal, shear force, and peel force. To enable belt-drive locomotion, a successful belt material will have a low peel force, and high shear force. To enable transitions at concavities, the material's shear adhesion will need to be significantly higher than its normal adhesion.

A long-term goal of this project is to take advantage of the dry adhesion methods currently being researched. It has been shown [Autumn, et al, 2002] that geckos, with billions of micro and nano-fibers on their toes take advantage of Van der Waals forces to strongly and temporarily adhere to various surfaces. Work has been done to create synthetic gecko-inspired fibers [Nortchen and Turner, 2005] but they are not yet flexible, reliable, or durable. Additionally, preliminary structures built from nanofibers have shown good adhesion properties to other materials, but poor adhesion to the same material.

In the absence of feasible dry adhesive materials, various polymers will be tested including polydimethyl siloxane (PDMS) and several durometers of Vytaflex urethane rubber.

A drawback of an adhesion based system for inter-module connection is the possibility of environmental contamination. The StickyBricks system will be tested in a clean environment, with the hope that next-generation dry adhesives will enable testing to move to real-world environments.

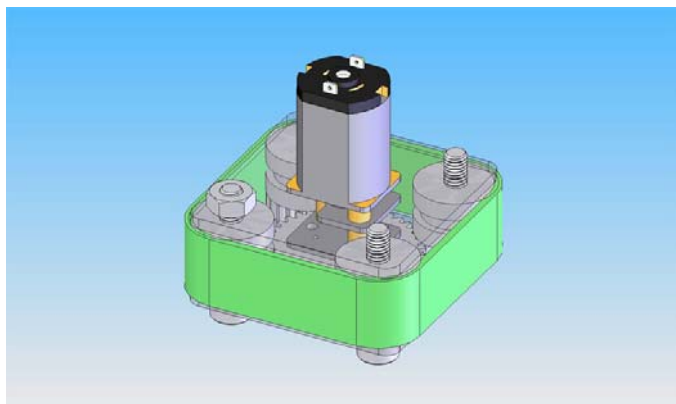


Figure 6: CAD drawing of a StickyBrick

#### IV. DESIGN CONSIDERATIONS

StickyBricks were designed and built iteratively, with the benefit of two manufacturing tools in our lab: a precision 40W laser cutter and a Stratasys Fused Deposition Modeling (FDM) machine. The speed at

which prototypes could be constructed contributed significantly to the design, allowing changes to be made quickly, and improving the design by enabling immediate, repeated experimentation.

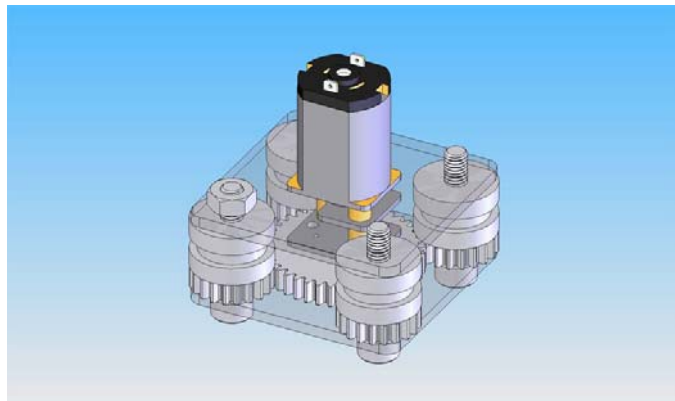


Figure 7: A StickyBrick without its drive belt

The two body plates are constructed out of .06" extruded acrylic sheet, and the five gear rollers were built using ABS plastic on the FDM machine. The bolts and nylon locking nuts are 18-8 stainless steel and thin discs of .010" thick electrical grade Teflon® PTFE act as bearings to reduce friction between the gears and body plates.

The motor is a 298:1 gear motor made by Sanyo, and is driven by a 5v regulated power supply. Specifications for the motor are provided in Table 1. For experimentation, the motor is simply wired to a reversing switch to allow a single StickyBrick to move forward and backward. Early testing confirms that the motor provides far more power than necessary for moving a single StickyBrick along the edge of an assembly.

|                       |                 |
|-----------------------|-----------------|
| No Load Speed         | 62 rpm          |
| Starting Torque       | 3300 gf-cm      |
| Weight                | 8.7 g           |
| Size                  | 10 x 12 x 29 mm |
| Noise                 | < 55 dB         |
| Voltage               | 5 V             |
| 200 g-cm load current | 95 mA           |
| Gear Reduction        | 297:1           |

Table 1: Sanyo 12G-A4S motor specifications

The adhesive drive belt was manufactured with Vytaflex 30® urethane rubber compound. Linear belt molds were built using FDM, and the urethane was poured by hand and allowed to set overnight. Cyanocrylate glue was used to bond the two ends of the belt into a loop. Several attempts were made to mold a

continuous circular belt, but manufacturing problems prevented success. While the glued joint works surprisingly well for testing, a continuous belt would improve motion stability and seems necessary for future work.

## V. RESULTS

At this point, results are promising but inconclusive. Early testing with drive belts of several durometers show that adhesive characteristics are of utmost importance to motion characteristics. Too much adhesion causes a StickyBrick module to rotate in place, and too little adhesion causes unreliable and inconsistent contact between the module and its substrate.

Limited success has been shown in driving a StickyBrick along a straight edge. A reliable test rig has not been implemented, so these successes are mostly sporadic and anecdotal. It seems probable that with further experimentation into belt materials and motor speeds, reliable StickyBrick locomotion could be achieved.

## VI. FUTURE WORK

An obvious drawback of the current StickyBrick design is its two-dimensional nature. A 3D StickyBrick is currently under development. By using dual belts, we can achieve a differential drive mechanism, allowing the belt to turn in place. By adding additional adhesive panels on the two non-drive sides of the "StickyCube," a stable lattice assembly can be maintained while still allowing for motion. It may be possible to design the additional adhesive panels to be retractable, allowing for the StickyCube to traverse channels only one module wide.

Research is also underway into better materials for the drive belt. Current research into gecko-inspired dry adhesives shows promise, and Sitti's group [8] is working on the manufacture of microfibers using PDMS. The flexibility of PDMS may make it a suitable material for the belt.

To prepare StickyBricks for further experimentation, it will be beneficial to remove the tether and provide on-board power. One 700mAh AAA rechargeable NiMH battery will fit next to the motor and provide enough power for up to an hour of experimentation. In addition, simple sensors will help to coordinate motion and planning among the modules. Infrared emitters and detectors mounted along the edges of each module would provide simple communication to keep modules aligned on a grid, and the current crop of Zigbee wireless transmitters could provide for communication

to a host PC.

## VII. CONCLUSION

Work on StickyBricks is by no means complete. We have designed and built several prototypes which address questions about feasibility, and more prototypes are necessary to examine other questions that have been raised in the process. We have demonstrated a small robotic module which can locomote using an adhesive belt on its perimeter, and outlined the next steps for development of a successful modular reconfigurable system.

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